CHAPTER 3

ENGINE MAINTENANCE

Keeping an internal combustion engine (diesel or gasoline) in good operating condition demands a well-planned procedure of periodic inspection, adjustments, maintenance, and repair. If inspections are made regularly, many malfunctions can be detected and corrected before a serious casualty results. A planned maintenance program will help to prevent major casualties and the occurrence of many operating troubles.

The Maintenance and Material Management (3-M) System provides a logical and efficient approach to many maintenance problems. It produces a large reservoir of information about equipment disorder and indicates what corrective steps must be taken to prevent them.

Another aspect that must be considered in connection with maintenance problems is the safety requirement aboard ship. On some ships, the 3-M System includes safety requirement cards. A safety requirement card provides guidelines and periodicity for the inspection of selected areas not covered in the regular maintenance schedule.

Complete information about the 3-M System is contained in the *Maintenance and Material Management (3-M) Manual,* OPNAVINST 4790.4.

There may be times when service requirements will interfere with a planned maintenance program. In such event, routine maintenance must be performed as soon as possible after the specified interval of time has elapsed. All necessary corrective measures should be accomplished as soon as possible. Repair jobs should not be allowed to accumulate, otherwise hurried and inadequate work will result.

Since the Navy uses many models of internal combustion engines, it is impossible to specify a detailed overhaul procedure that would be adaptable to all models. However, there are several general rules which apply to all engines. They are:

1. Detailed repair procedures are listed in manufacturers' instruction manuals and in maintenance pamphlets. Study the appropriate manuals and pamphlets before attempting any repair work. Pay particular attention to tolerance limits, and adjustments.

2. Observe the highest degree of cleanliness in handling engine parts during overhaul.

3. Before starting repair work, be sure that all required tools and replacements for known defective parts are available.

4. Keep detailed records of repairs. Such records should include the measurements of parts, hours in use, and the names of the new parts installed. Analyses of such records will indicate the hours of operation that may be expected from the various engine parts. This knowledge is helpful as an aid in determining when a part should be renewed in order to avoid a failure.

Since maintenance cards, the manufacturers' maintenance manuals, and the various types of instructions discuss repair procedures in detail, this chapter will be limited to general information on engine inspections, adjustments, and maintenance, as well as some of the troubles encountered during overhaul, the causes of such troubles, and the methods of repair to be used.

INSPECTIONS

Inspections and maintenance are vital in order to maintain engines (diesel and gasoline) in

proper operating condition and to minimize the occurrence of casualties caused by material failure.

A comparatively minor engine malfunction, if not recognized and remedied in its early stages, might well develop into a major casualty. You and your work center personnel must be able to recognize the symptoms of any developing malfunction by using your senses of sight, hearing, smell, or even touch or feel (heat/vibration).

Your personnel must be trained to pay particular and continuous attention to the following indicators of oncoming malfunctions:

1. Unusual noises
2. Vibrations
3. Abnormal temperatures
4. Abnormal pressures
5. Abnormal operating speeds

All operating personnel should thoroughly familiarize themselves with the specific temperatures, pressures, and operating speeds of equipment that are required for normal operation, so that any departure from the normal will become more readily apparent.

If a gage, or other instrument for recording operating conditions of machinery, gives an abnormal reading, the cause of the malfunction must be fully investigated. Normally the installation of a spare instrument, or a calibration test, will quickly indicate whether the abnormal reading is due to instrument error. Any other cause must be traced to its source.

Because of the safety factor commonly incorporated in pumps and similar equipment, considerable loss of capacity can occur before any external evidence is apparent. Changes in the operating speeds (from those normal for the existing load) of pressure-governor-controlled equipment should be viewed with suspicion. Most variations from normal pressures, lubricating oil temperatures, and system pressures indicate either inefficient operation or poor condition of machinery.

When a material failure occurs in any unit, a prompt inspection should be made of all similar units to determine whether there is any danger that a similar failure might occur in other units. The cause of the failure must also be determined and corrected in order to avoid repeated failure of the same or similar components. Prompt inspection may eliminate a wave of repeated casualties.

Strict attention must be paid to the proper lubrication of all equipment, including frequent inspection and sampling to ensure that the correct quantity of the proper lubricant is in the unit. It is good practice to make a daily check of samples of lubricating oil in all auxiliaries. Such samples should be allowed to stand long enough for any water to settle. When auxiliaries have been idle for several hours, particularly overnight, a sufficient sample to remove all settled water should be drained from the lowest part of the oil sump. Replenishment with fresh oil to the normal level should be included in this routine.

The presence of saltwater in the oil can be detected by drawing off the settled water by means of a pipette and by running a standard chloride test. A sample of sufficient size for the test can be obtained by adding distilled water to the oil sample, shaking it vigorously, and then allowing the water to settle before draining off the test sample. Because of its corrosive effects, saltwater in the lubricating oil is far more dangerous to a unit than is an equal amount of freshwater. Saltwater is particularly harmful to units containing oil-lubricated ball bearings.

The information given so far relates to the inspections that Enginemen make on operating engines (either diesel or gasoline). Since the Navy uses more diesel than gasoline engines the remainder of this chapter will deal with diesel engines and with the inspection and maintenance procedures that are required by the planned maintenance system (PMS) and the manufacturers' technical manuals.

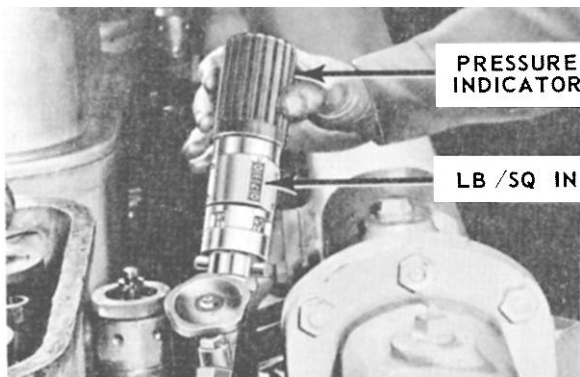## COMPRESSION AND FIRING PRESSURES

Readings of the compression and firing pressures must be taken every 200 hours for the trend analysis graphs. They may also be taken at other times when engine operating conditions require additional monitoring such as when an engine misfires, fires erratically, or when any one cylinder misfires regularly. There can be many reasons for an engine to misfire, some of these are a clogged air cleaner/filter, an engaged fuel

cutout mechanism, or a loss of compression. If, after checking the air cleaner, the filter, and the fuel cutout mechanism, you determine that the problem is due to loss of compression, then you must perform a compression check with a cylinder pressure indicator.

There are several different types of indicators that may be used. Most indicators used with diesel-cylinder engines are either of the spring balanced type or the trapped pressure type. They are manufactured by various companies such as Kiene, Bacharach, and Kent-Moore. Some of these indicators measure only compression pressure, others measure both compression and firing pressures.

Spring Balanced Indicator

A spring balanced indicator, such as the one manufactured by Bacharach (figure 3-1), employs a spherical ball piston, which is held on its seat by the force of a helical spring actuated by the cylinder pressure which acts against the bottom of the ball piston to oppose the spring tension. Before the indicator is attached to the engine, the vulcanized handle must be rotated clockwise until the reading on the counter is greater than the maximum cylinder pressure expected. The amount of this pressure is listed in the engine manufacturer's technical manual. When the indicator is installed, the operator must make sure that it is placed as near the cylinder as possible and position it so that it can be read easily. After the indicator is installed the engine is operated at the specified rpm, then the fuel to the cylinder

being tested is cut out, the cylinder test cock is opened, and the spring tension on the indicator is adjusted. The tension of the spring is reduced by rotating the vulcanized handle counterclockwise until the maximum cylinder pressure barely offsets the spring pressure. At this point, the latch mechanism of the indicator trips and locks the handle firmly in position, giving a direct and exact reading of the pressure in pounds per square inch (psi). To reset the lock mechanism for a new reading, the handle must be rotated counterclockwise one-fourth turn. When this indicator is stowed for future use, the indicator spring must be unloaded by rotating the handle counterclockwise until a zero pressure reading is obtained.

Trapped Pressure Indicators

In this type of indicator, the cylinder gases enter past a valve into a chamber which leads to a gage. When the pressure above the valve equals that of the cylinder, the valve seats and traps the gas above the valve at its highest pressure, then this pressure is read on the gage. There are several other types of indicators. The one pictured in figure 3-2 is used to take compression readings

PRESSURE
INDICATOR

LB /SQ IN

75.238X
Courtesy of Bacharach, Inc., USA

Figure 3-1.-Spring balanced Pressure Indicator.
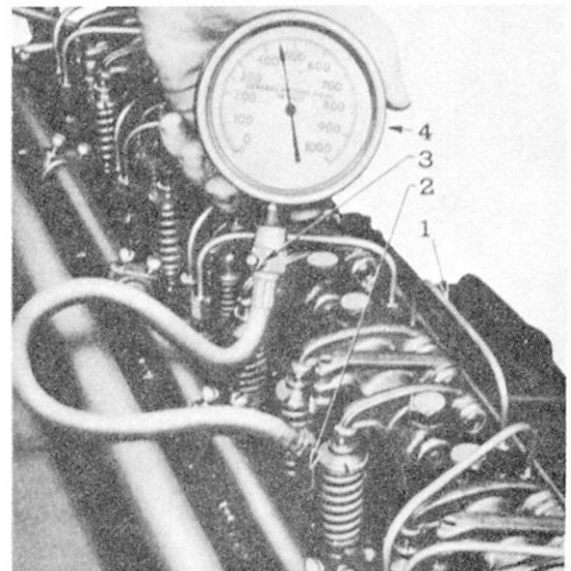
1. FUEL JUMPER   3. BLEED VALVE
2. COMPRESSION ADAPTOR FITTING   4. GAGE

75.238X
Courtesy of Bacharach, Inc., USA

Figure 3-2.—Trapped Pressure Indicator (small boat).

only on engines installed on small boats. Engines like the GM-6-71 do not have indicator cocks installed.

When taking compression readings on a 6-71 engine, you will perform the following steps:

1. Check the manufacturer's technical manual for the minimum compression pressure required for the engine.

2. Start the engine and run it at approximately one-half the rated load until normal operating temperatures are reached.

3. Stop the engine and remove the fuel pipes from the injector and the fuel connectors on the cylinder to be tested.

4. Remove the injector and install the indicator adapter, with pressure gage attached, and use the crab nut to hold the adapter in place.

5. Use a space fuel pipe to fabricate a jumper connection between the fuel inlet and the return manifold connectors to by-pass fuel to and from the injector.

6. Start the engine again and run it at approximately 600 rpm.

7. Observe and record the compression pressure as indicated on the gage.

Another type of trapped pressure indicator is the Kiene indicator (figure 3-3). This indicator is basically a Bourdon gage connected to a cylindrical pressure chamber. The pressure chamber contains a check valve which allows the gas to

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Courtesy of Bacharach, Inc., USA

Figure 3-3.—Trapped Pressure Indicator.

flow from the engine into the chamber until the pressures are equalized. This gage is attached to the chamber and the pressure is read directly. The check valve is an inverted piston seating on a seat piece. The valve moves up and down in a guide. A stop nut is used to adjust the travel of the check valve.

Most of you should become familiar with this indicator since it is widely used to check both the compression and firing pressures on main diesel engines and emergency generator diesel engines. Review figure 3-4A and B. It is a PMS situation requirement to be performed when the engine operating conditions indicate problems.
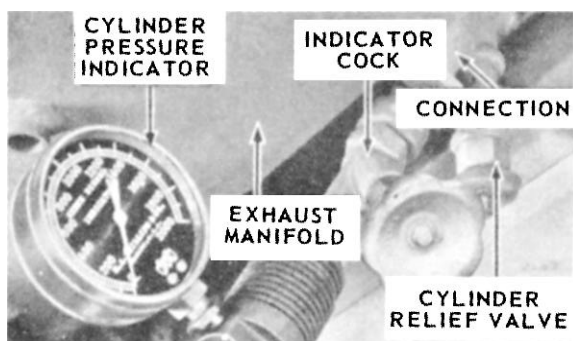
EXHAUST AND CYLINDER TEMPERATURES

One of the most useful tools that the engine operator has for monitoring an engine's performance is the thermocouple pyrometer. The principal use of this device is in the exhaust system (but it can also be used for other purposes) where it is used to measure the exhaust gas temperatures at each cylinder or the common temperature in the exhaust manifold. By comparing the exhaust gas temperatures of each cylinder, the operator can determine if the load is balanced throughout the engine.

The two types of pyrometers in use are the fixed installation and the portable hand-held instrument (figure 3-5). Both types use a thermocouple unit, such as the one shown in figure 3-5, installed in the exhaust manifold.

In its simplest form, a thermocouple consists of two dissimilar metal wires, usually iron and constantan (55% copper and 45% nickel) that are joined at both ends to form a continuous circuit. When the temperatures at the junctions are different an electrical current is produced and flows in the circuit. The greater the temperature difference, the greater the voltage produced.

One junction, known as the hot junction, is contained in a closed-end tube, installed in the exhaust manifold of each cylinder. The other junction called the cold junction, is exposed to room temperature, and is located at the pyrometer wire

(Ref. Figure (cont))

    (1) Open No. 1 cylinder test cock and blow out test cock; shut test cock.
    (2) Install indicator.
    (3) Open cylinder test cock and record firing pressure; maximum firing pressure is 900 to 1100 psi.
    (4) Shut cylinder test cock and vent the indicator.
    (5) Remove indicator from test cock.
    (6) Repeat steps 1.c.(1) through 1.c.(5) for remaining cylinders.
  d. Stop engine and line up for automatic operation.

MAINTENANCE REQUIREMENT CARD (MRC)
OPNAV 4700 ( ) (Rev)

Figure 3-4B.—MRC-for measuring compression and firing pressures (back).

SHIP SYSTEM	SUB-SYSTEM	MRC CODE		
		A-2	R-5	M/H

SYSTEM	EQUIPMENT	RATES	M/H
	Emergency Generator Diesel Engine	EN1	1.0
		EN3	1.0

MAINTENANCE REQUIREMENT DESCRIPTION	TOTAL M/H	ELAPSED TIME
1. Measure compression and firing pressures.	2.0	1.0

SAFETY PRECAUTIONS

1. Forces afloat comply with Navy Safety Precautions for Forces Afloat, OPNAVINST 5100 series.
2. Wear gloves when handling indicator.

TOOLS, PARTS, MATERIALS, TEST EQUIPMENT

1. Kiene indicator
2. Asbestos gloves
3. Pencil and paper
4. Injector lockout wrench, mfr part No. 3385742

PROCEDURE

NOTE: Accomplish when directed as result of engine operating condition.

Preliminary
  a. Ensure engine is at normal temperature and operating at full speed and no load.

1. Measure Compression and Firing Pressures.
  a. Measure compression pressures.
    (1) Remove cover from cylinder being tested.
    (2) Open cylinder test cock to blow out passage; shut test cock.

WARNING: Wear gloves when handling indicator.

    (3) Attach indicator to test cock.
    (4) Install lockout wrench and lock out the injector.
    (5) Open indicator vent and cylinder test cock.
    (6) Shut indicator vent and adjust indicator for minimum vibration.
    (7) Record compression pressure and shut cylinder test cock; normal compression pressure is 550 psi to 650 psi.
    (8) Remove injector lockout wrench.
    (9) Repeat steps 1.a.(2) through 1.a.(8) for each remaining cylinder under cover removed in step 1.a.(1), if applicable.
    (10) Reinstall cylinder cover.
    (11) Repeat steps 1.a.(1) through 1.a.(10) for remaining cylinders.
  b. Operate engine at full speed and full load.
  c. Measure firing pressures.

LOCATION			DATE
			May 1980

MAINTENANCE REQUIREMENT CARD (MRC)
OPNAV 4700 ( ) (Rev)

Figure 3-4A.—MRC-for measuring compression and firing pressures (front).

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Figure 3-5.—Pyrometers used in diesel exhaust systems.

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Figure 3-6.—Sectional view of a thermocouple.

terminals (see figure 3-6). A pyrometer (millivolt meter) measures the voltage produced and shows the results on a scale which has been calibrated to read in degrees of temperature. In fixed installation pyrometers, if the connecting wires are of the same type as those of the thermocouples, the thermocouple element becomes, in effect, extended to the pyrometer terminals and the temperature at the meter (now the cold junction) becomes the reference temperature. Then the selector switch can be rotated to any cylinder and contact can be made between the pyrometer and the hot junction. A reading can then be obtained for that particular point.

The hand-held pyrometer consists of an indicator and a pair of pointed prods attached to a sub-base and supported by a handle. To obtain a reading, the prod points are pressed against the exposed thermocouple terminals. The reading is taken from the scale. A point to remember is that the zero adjuster must be set to indicate room temperature rather than 0° temperature.

GRAPHIC RECORDS

As you read in chapter 2, graphic records play an important part in keeping an engine in proper operating condition. When used properly they can tell you how your engine is performing and what is happening inside the engine. Graphic records indicate the overall condition of an engine and warn you when certain parts are beginning to wear out so that you may take prompt corrective actions and prevent major casualties.

ADJUSTMENT AND MAINTENANCE

An internal combustion engine is a complicated machine, built with a high degree of precision throughout and capable of long dependable service if it is kept in good operating condition.

To keep an engine in good operating condition you must perform all the adjustments and maintenance prescribed in your installed PMS and the manufacturers' technical manuals. In this section you will read about the adjustment and maintenance of various components of an internal combustion engine.

AUTOMATIC REGULATING VALVE

In many engines, freshwater temperature is regulated by an automatic regulating valve which maintains the freshwater temperature at any desired value by bypassing a portion of the water around the freshwater cooler. An automatic temperature regulator of the type commonly used in the cooling systems of marine engines is shown in figure 3-7. Even though these regulators are automatic (self-operated), provisions are included in most installations for manual operation in the event that the automatic feature fails.
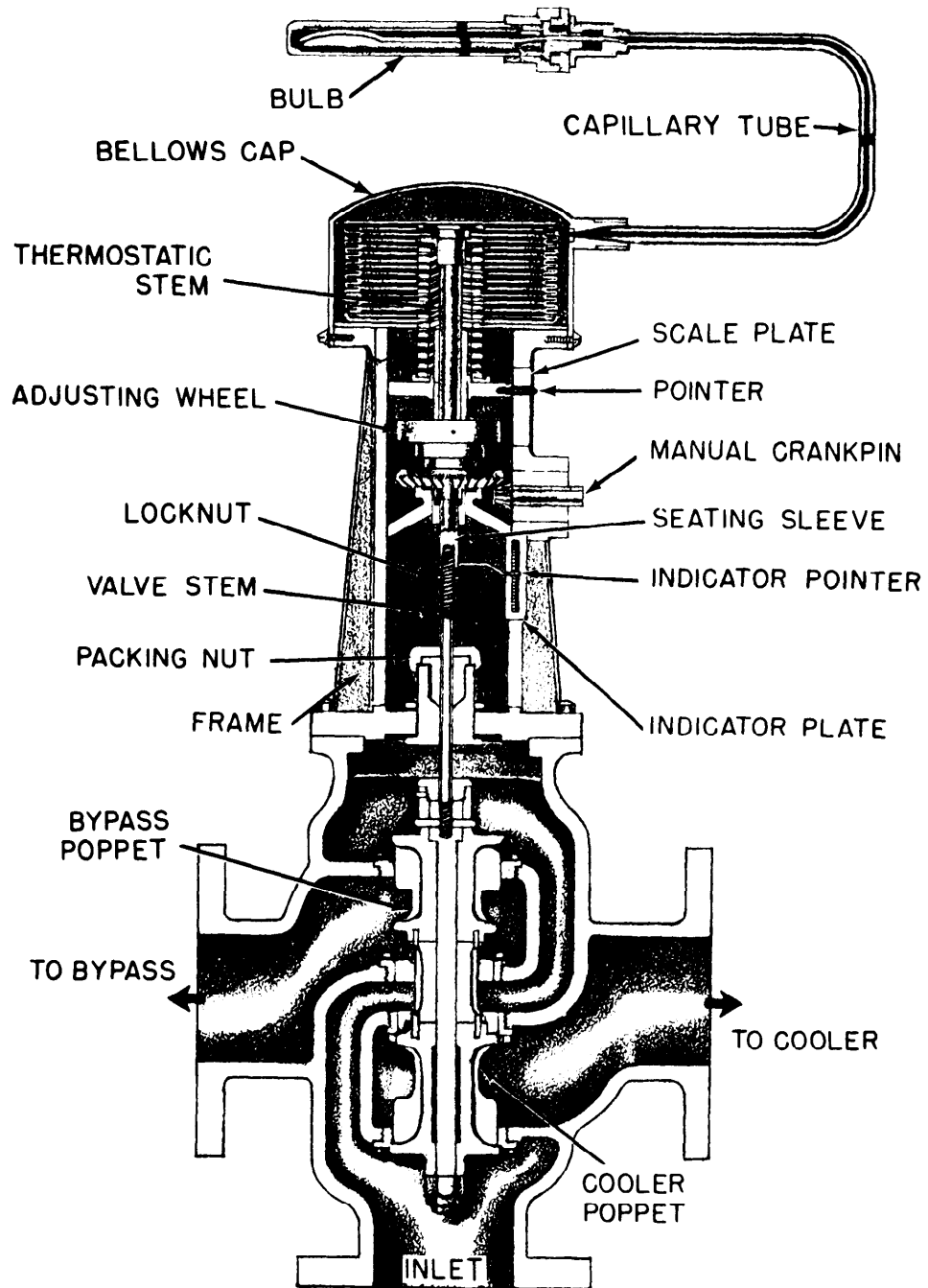
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Figure 3-7.—Automatic temperature regulator.

The temperature regulator consists of a valve and a thermostatic control unit mounted on the valve. The thermostatic control unit consists of a temperature-control element and a control assembly.

The temperature-control element is essentially two sealed chambers consisting of a bellows connected by a flexible armored capillary tube to a bulb mounted in the engine cooling-water discharge line. One chamber is formed by the bellows and cap, which are sealed together at the bottom; the other chamber is in the bulb. The entire system (except for a small space at the top of the bulb) is filled with a mixture of ether and alcohol which vaporizes at a low temperature. When the bulb is heated, the liquid vaporizes and the pressure within the bulb increases. This forces the liquid out of the bulb and through the capillary tube to the bellows. As the bellows is moved down, it operates the valve.

The control assembly consists of a spring-loaded mechanical linkage which connects the temperature-control element to the valve stem. The coil spring in the control assembly provides the force necessary to balance the force of the vapor pressure in the temperature-control element.

Thus, the downward force of the temperature-control element is balanced, at any point, by the upward force of the spring. This permits the valve to be set to hold the temperature of the engine cooling water within the allowed limits.

The regulator operates only within the temperature range marked on the nameplate; it may be adjusted for any temperature within this range. The setting is controlled by the range-adjusting wheel, located under the spring seat. A pointer attached to the spring seat indicates the temperature setting on a scale which is attached to the regulator frame. The scale is graduated from 0 to 9, representing the total operating range of the regulator.

The location of a temperature regulator may be located in either the seawater or freshwater circuit. In most engines, the regulator is located in the freshwater circuit.

When located in the seawater circuit, the regulator controls the amount of seawater flowing through the coolers. As the temperature of the freshwater becomes greater than the temperature for which the regulator is set, the regulator actuates a valve to increase the flow of seawater through the coolers. On the other hand, when the freshwater temperature is below the temperature for which the regulator is set, the regulator actuates the valve and decreases the flow of seawater through the coolers.

In installations where the regulator is in the freshwater circuit, water is directed to the cooler when the temperature of the water is above the maximum setting of the regulator. After passing through the cooler where the temperature of the water is lowered, the water returns to the suction side of the freshwater pump to be recirculated. When the temperature of the water is below the maximum setting of the regulator, the water bypasses the cooler and flows directly to the suction side of the pump. Bypassing the cooler permits the water to be recirculated through the engine; in this way, the temperature of the water is raised to the proper operating level.

Regardless of whether the regulator is in the fresh or seawater circuit, the bulb which causes the regulator to operate is located in the freshwater discharge line of the engine.

Temperature regulators not only control the temperature of the freshwater but also control indirectly the temperature of the oil discharged from the lubricating oil cooler. Control of the lubricating oil temperature is possible because the water (freshwater or saltwater) that is passed through the regulator and the freshwater cooler is also the cooling agent for the lubricating oil cooler. When the lubricating oil is cooled by seawater, two temperature regulators are installed in the seawater circuit. The temperature regulator bulb of the regulator that controls the temperature of the freshwater is installed in the freshwater circuit; the bulb of the regulator that controls the temperature of the lubricating oil is installed in the lubricating oil system.

Maintenance

To allow proper operation of a temperature regulator, the valve stem must not bind in the stuffing box, but must move freely. The valve stem must be lubricated frequently where it enters the stuffing box and also around the threaded sleeve used for the manual control. A small amount of grease should also be used on the bevel

Figure 3-8.—Figure Removed.

gears. The valve packing nut should be kept only finger tight and should be lubricated occasionally with a drop of oil. Should it become necessary to renew the packing, you will need to remove the nut, take out the packing gland, clean the stuffing box, and repack it with asbestos wicking saturated with oil.

Should the temperature of the freshwater leaving the engine be too high when the regulator is set on the lowest adjustment setting you should do the following:

1. Ensure that the manual pointer is set at the THERMOSTATIC position.

2. Ensure that the packing gland is not binding the valve stem and that the valve stem is

not stuck in the COOLER CLOSED (minimum cooling) position.

3. Check the water lines for other causes of the difficulty. If this check does not reveal the cause of the trouble, it is probable that the temperature control element is inoperative, and that it should be checked.

If undercooling occurs when the temperature regulator is set on the highest adjustment setting, check for a sticking valve in the BY-PASS CLOSED (maximum cooling) position. Sticking may be caused by a tight stuffing box or by dirt under the lower valve seat. If the temperature at the bulb is lower than the set temperature and the valve position indicator shows COOLER

CLOSED, excessive leakage is indicated. In such case you will have to regrind the valve using the following procedure:

1. Disconnect the valve from the piping.
2. Remove the packing nut and the packing.
3. Disconnect the valve stem and remove the locknut from the thermostatic stem.
4. Remove the thermostatic control unit from the valve.
5. Clean the valve stem until it is smooth. If necessary, polish it with fine emery cloth.
6. Grind the valve seats until a perfect seal is obtained; then remove all grinding compound from the valve and the seats.
7. Reassemble the valve and the control unit.
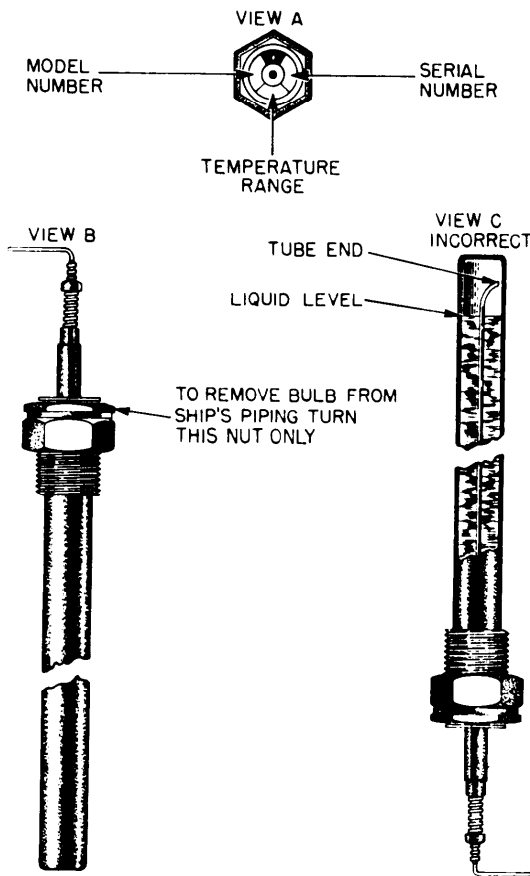8. Repack the stuffing box and lubricate it with engine oil.

9. Secure the packing gland nut finger tight.
10. Insert the bulb into the ship's piping in either a horizontal or vertical position, as shown in views A and B of figure 3-9. When the bulb is installed in the vertical position, the nut must be at the top; when it is installed in the horizontal position, the arrow on the indicator disk must point upward. NEVER INSTALL THE BULB WITH THE NUT AT THE BOTTOM (as shown in view C of figure 3-9) because in this position the liquid would be below the end of the internal capillary tube and would have little or no effect on the bellows of the temperature regulator valve.
11. Adjust the regulator.

Adjustment

A closeup of the adjusting and indicating features of the temperature regulator is shown in figure 3-10. The procedure for adjusting a temperature regulator is as follows: Rotate the manual crank pin until the indicator pointer is in
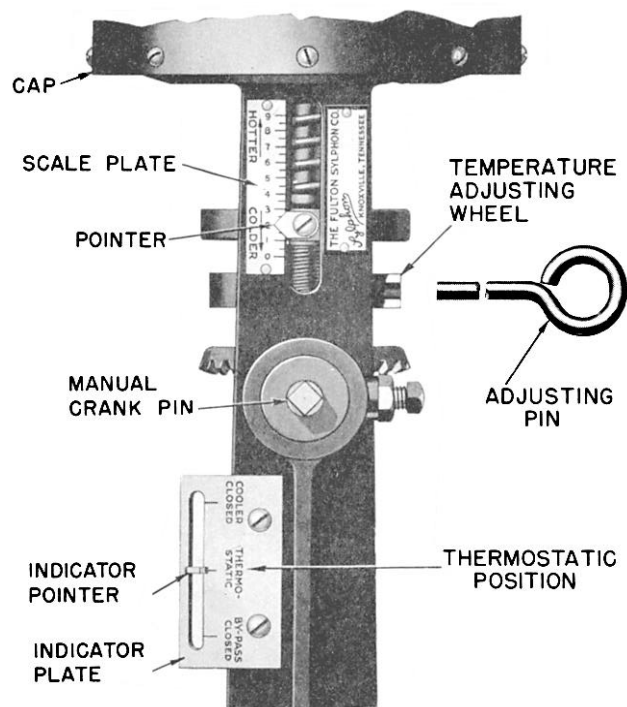

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Figure 3-9.—Bulb installation.

75.224

Figure 3-10.—Scale and Indicator plates of temperature regulator.

the THERMOSTATIC POSITION. Turn the adjusting wheel until the pointer is opposite 2 on the scale plate. Loosen the locknut and unscrew the valve stem until it is free of the thermostatic stem. Then turn the adjusting wheel until the pointer is opposite 8 on the scale plate. (Note: The preceding steps should be performed with the thermostatic bulb removed from the ship's piping and when the bulb temperature is below 100°F.)

Again rotate the manual crankpin until the lower end of the seating sleeve is flush with the lower end of the thermostatic stem. With the seating sleeve and the indicator pointer in this position, loosen the screws in the indicator plate and slide the plate up or down as needed to align the THERMOSTATIC mark in the center of the plate with the indicator pointer. Then retighten the screws. (The marks COOLER CLOSED and COOLER BY-PASS on the indicator plate are only approximate.) Screw the valve stem into the thermostatic stem and turn it until the cooler poppet valve seats firmly. Turn the adjusting wheel until the pointer is opposite 2 on the scale plate. Turn the valve stem one full turn into the thermostatic stem and retighten the locknut.

With the manual control on the THERMOSTATIC position, turn the adjusting wheel in a direction to bring the pointer to number 9 on the scale plate. Run the engine at warmup speed until the temperature of the fluid, as indicated by the thermometer in the line with the thermostatic bulb, rises to the desired temperature. (The desired temperature must be determined in advance from applicable instructions.)

With the engine running at warmup speed and the temperature at the thermostatic bulb at the desired value, turn the adjusting wheel until the cooler poppet just begins to leave its seat. This action is shown by the movement of the mark on the valve stem downward from the COOLER CLOSED mark on the valve position indicator. Valves adjusted in accordance with this procedure will normally maintain the temperature of the fluid at the thermostatic bulb between the desired value and a temperature approximately 20° higher, under any conditions of engine load or injection temperature. This 20° difference is the temperature rise required to cause the poppet valve to move through the necessary travel.

HEATING EXCHANGER DEFINITIONS

Problems with the cooling system of an engine may prevent the cooling system from keeping the engine parts and working fluids at safe operating temperatures. Failure of the system may lead to several of the troubles and casualties that have been discussed earlier.

In marine installations, lubricating oil and most of the engine parts are cooled by the circulation of seawater, freshwater, or both. When the cooling of an engine part is mostly by oil spray or oil circulation, the oil is cooled by circulation through an oil cooler. Figure 3-11 illustrates a cooling system in which both freshwater and seawater serve as coolants.

When maintaining engine cooling water temperatures within specified limits, the principal difficulties you may encounter are in maintaining circulating pumps in operating condition; preventing corrosion; reducing the cause of scale formation in water jackets and heat exchangers; cleaning jackets and heat exchangers according to proper procedures; and in preventing leaks in the various parts of the system.

The coolers (or heat exchangers) which remove the heat from the cooling water of an engine may vary considerably in design. Those used in cooling systems may be classified basically as the radiator type and the tubular type. The radiator is sometimes referred to as the strut or the Harrison type, while the tubular is identified as the Ross or shell-and-tube type. A heat exchanger of both types is shown in figure 3-12. The heat exchanger on the top of the picture is a radiator type heat exchanger; the one on the bottom is a tubular-type heat exchanger. In heat exchangers of the radiator type, the freshwater passes through the tubes and the seawater passes around them. In the tubular type, the freshwater surrounds the tubes and the seawater passes through them.

CASUALTIES

Although heat exchangers vary in design, they are all subject to similar casualties. The principal difficulties which may prevent heat exchangers from functioning properly are excessive scale deposits on the cooler element, clogged cooler elements, or cooler leakage.
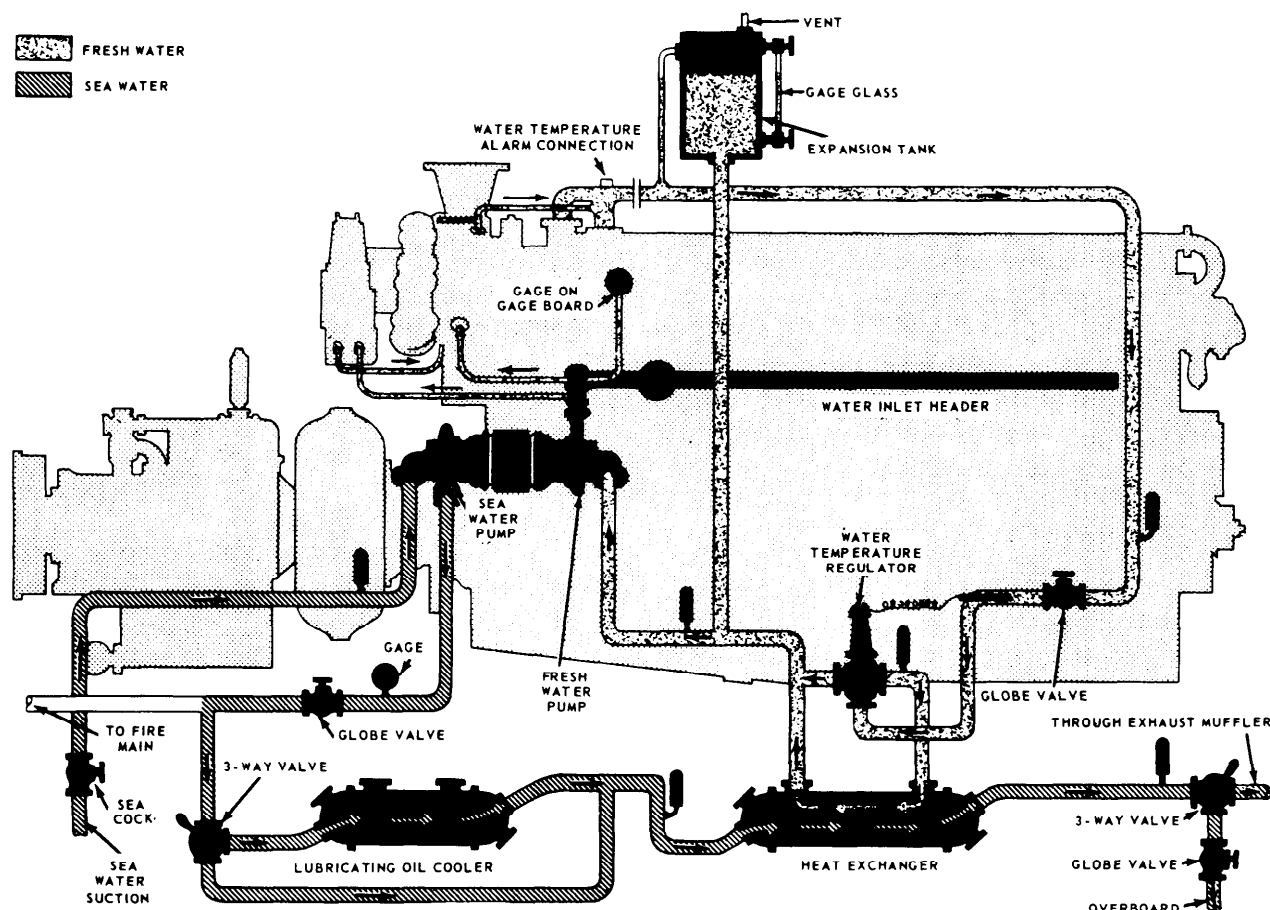
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Figure 3-11.—A cooling water system.

A gradual increase in the freshwater temperature is usually an indication of EX-CESSIVE SCALE on a cooler element. As scale formation increases, there is a gradual increase in the pressure difference between the inlet and outlet of the heat exchanger. Scale deposits generally form faster on the saltwater side than on the freshwater side, because of the greater amount of dissolved salt present in the water.

Complete prevention of scale formation is not possible, but steps can be taken to reduce its formation by using proper cleaning methods and procedures. Seawater discharge temperature should be maintained below a specified limit (130°F), because the rate of scale formation is increased as the temperature increases. The water used in

closed cooling systems must be as pure as possible. Distilled water is recommended for a freshwater cooling system, but since distilled water is not absolutely pure, additional steps must be taken to control acidity and alkalinity. The treatment used to control these factors will not remove scales already formed, but it will prevent further precipitation of scale-forming slats. You will find details for water treatment in closed water systems in chapter 233, *NAVSHIPS Technical Manual,* and in most engine instruction manuals.

Not only the hard deposits chemically precipitated from the circulating water, but also such items as marine life, grease, and debris of various types may CLOG OR RESTRICT COOLER ELEMENTS. The principal causes of
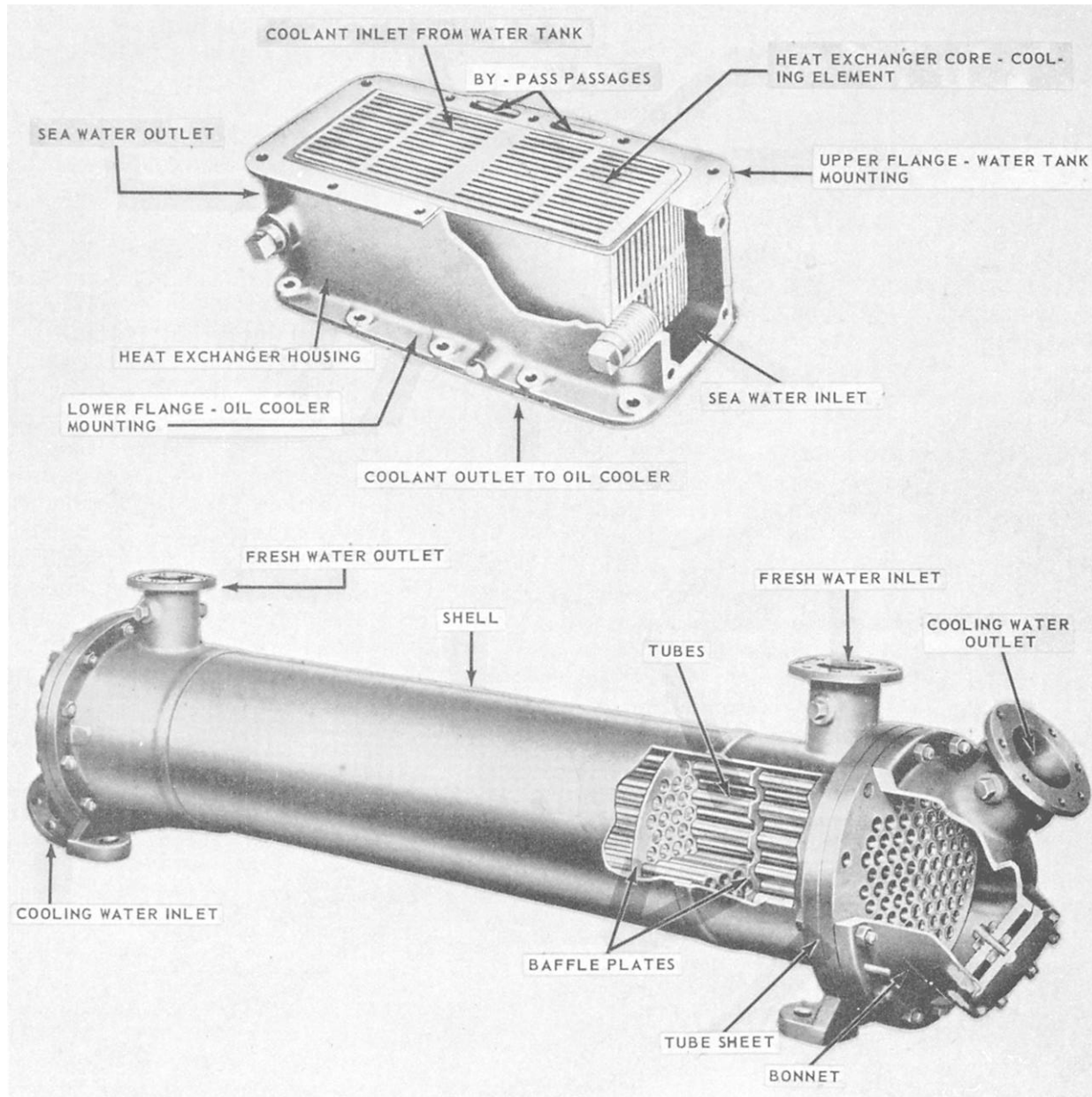
Figure 3-12.—Types of heat exchanges.

cooler clogging by loose foreign matter are faulty seawater strainers, dirty freshwater, excessive lubrication of the pumps, and leaking oil coolers.

To prevent the entry of sea debris, a punctured screen in a seawater strainer must be replaced as soon as possible. Obviously, the use of dirty freshwater will hasten the clogging of a cooler element. Grease and oil may enter the cooling system and the film deposited on the cooler element will reduce the capacity of the cooler. Grease may

come from grease cups which are used on some water pumps to lubricate bearings. If the cups are turned down too much or too often, grease is forced into the circulating water. A hole in the element of an oil cooler permits oil to flow into the cooling system. Any source of oil or grease should be located and repairs made as soon as possible.

Corrosion or erosion of the element in a heat exchanger, as well as operation at excessive pressure, may cause LEAKS. These leaks can develop either in the element or in the casing. Leakage from the cooler casing can usually be detected by inspection. Element leaks, however, are more difficult to detect. Any noticeable decline or rise in the freshwater tank level, with the temperature remaining normal, usually indicates leakage.

A hole made by corrosion in a cooler element indicates that corrosion probably exists throughout the element, and a thorough inspection should be made. Corrosion can be prevented to a large extent by using the prescribed freshwater treatment, inspecting as necessary and venting the cooler to remove entrapped air.

Holes due to erosion are usually caused by particles of grit (sand, dirt, etc., resulting usually from operation in shallow water) striking an element at high velocity. Grit is for the most part so fine that it passes easily through the strainer. If the strainer is defective, even the larger particles of grit may enter the cooler.

Erosion by water at high velocity may also result in holes in a cooler element. This occurs when water flow has to be increased above the rated capacity in order to maintain a desired freshwater temperature. Whenever it is found necessary to greatly increase the water flow, the cooler should be cleaned.

If the designed maximum operating pressure (indicated on the exchanger name plate) is exceeded, leaks are apt to result. Excessive pressure is likely to occur in conjunction with clogging, because additional pressure is necessary to force a given quantity of water through a clogged element.

MAINTENANCE AND REPAIR

Because of the difference in their construction, methods of cleaning both types of heat exchangers (radiator and tubular) differ in some respects. Radiator-type heat exchangers are cleaned by chemical means because mechanical cleaning is not satisfactory for this type heat exchanger. Chemical cleaning of radiator-type units is discussed in *Engineman 3 & 2,* NAVEDTRA 10541 (current edition). Tubular heat exchangers, on the other hand, are cleaned by mechanical means.
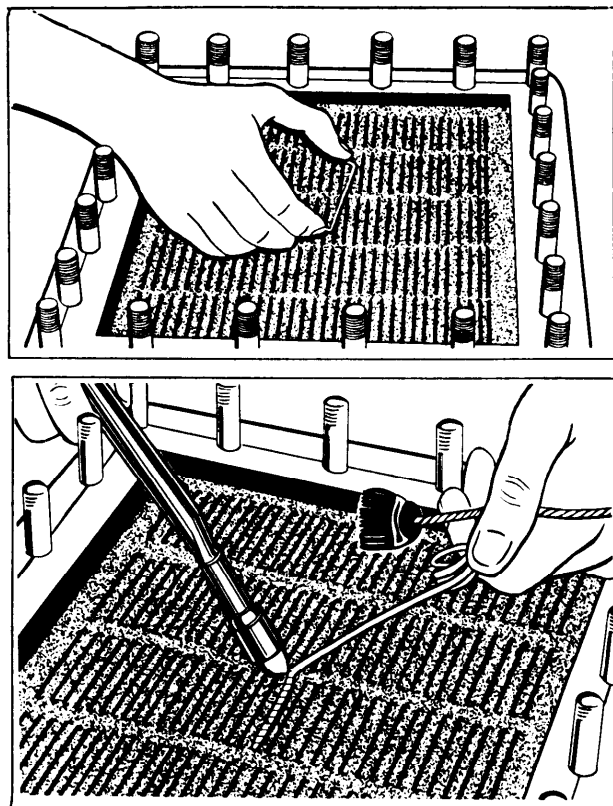
In both types of heat exchangers, loose foreign matter such as seaweed, sand, and dirt may be removed by blowing steam through the element in a direction opposite to the normal flow of water. When an element is badly clogged, care must be exercised not to admit steam at a pressure exceeding the maximum specified for the element. If a film of oil or grease is evident, the element should be cleaned like an oil cooler element.

Leakage from the CASING of a radiator-type heat exchanger may be caused by a damaged gasket. If so, the heat exchanger should be removed from the piping in order that flange faces may be tightened evenly after a new gasket is installed. If there is any reason to suspect that there are leaks in a heat exchanger element, the best method for locating them is by an air test. This test may be accomplished as follows:

1. Remove the element from the casing.
2. Block off the discharge side of the element.
3. Attach a pressure gage to the inlet line of the element.
4. Supply low-pressure air to the inlet side of the element. Remember: <u>Air pressure must NEVER exceed design pressure for the element.</u>
5. Immerse the element in a tank of water.
6. Check for bubbles.

An element of a heat exchanger may also be tested hydrostatically by filling the element with water under pressure and checking for leaks.

Emergency repair of leaks in the element of a radiator-type heat exchanger can be made as shown in figure 3-13. When emergency repairs to the radiator-type heat exchanger are necessary, they may be made with the use of soft solder and a small torch or soldering iron. Extreme care must be taken to prevent the surrounding area from being overheated, thus causing the existing solder to melt. Small radiator-type heat exchangers

further corrosion. Removing the tarnish will also reduce the tube wall thickness and over a period of time and a number of cleanings, could sufficiently reduce tube strength, resulting in tube failure. For the proper procedures for cleaning shell and tube type heat exchangers and the safety precautions, use the PMS maintenance requirements cards, the manufacturer's technical manual and *Naval Ships's Technical Manual,* chapter 254.

LUBRICATING SYSTEM

To ensure that all the parts of an engine receive adequate lubrication, it is essential that all parts of the lubricating oil system be properly maintained at all times. Some parts which may be a source of trouble are considered in this section. For other information on lubricating systems, see *Engineman 3 & 2,* NAVEDTRA 10541 (current edition).

LUBE OIL PUMPS

Pumps used in engine lubricating systems are of the positive displacement type. In some pumps pressure control is maintained by pressure regulating or pressure relief valves built directly into the pump; in other pumps, valves exterior to the pump are used for this purpose. Most regulating devices recirculate excess lube oil back to the suction side of the pump, but some pumps discharge excess oil directly into the engine sump.

Pump casualties, as well as many other lube systems failures, are indicated by the loss of lube oil pressure. The loss of oil pressure can be recognized by checking the pressure gages at prescribed intervals, or by means of an electrical alarm system. Most lube oil pump failures are generally due to wear, and develop gradually. Failures may also occur abruptly if a drive shaft breaks, or some parts suffer physical deformation. Such failures are usually indicated by abnormal noise in the pump and by sounding of the low-pressure lube oil alarm.

The warning system should be tested at specified intervals, usually when an engine is being started or secured. Warning systems do not excuse personnel from their responsibility for keeping a vigilant and accurate watch on engine

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Figure 3-13.—Emergency repair of a tube leak in a radiator type heat exchanger.

should be replaced as soon as a leak develops, if a replacement is available. The presence of one leak, unless caused by dropping or accidental puncture, indicates that other areas in the heat exchanger may be eroded.

In shell-and-tube heat exchangers, a leaking tube must be replaced as soon as possible. In an emergency, a faulty tube may be blocked off by inserting a special plug at each end, until the tube can be replaced. An air lance or water lance should be used to clean the tubes of a shell-and-tube heat exchanger. If the scale has hardened in the tubes, a round bristle brush or soft rubber plugs may be used to clean the tubes. When cleaning the tubes by mechanical means, avoid damaging the protective coating inside the tubes. These tubes should never be polished, as the tarnish on the tubes acts as insulation to prevent

instruments. The instruments give the most reliable indication as to what an engine is doing and what adjustments should be made.

OIL LINES AND PASSAGES

Troubles occurring in the oil passages and oil lines are usually in the form of plugged or cracked lines. The former is generally the result of carelessness, while the latter is usually a result of improper support of the line.

Even though clogged passages may be indicated by increased pressure gage readings, it is dangerous to rely wholly on such indications, since stoppage occurring beyond the pressure regulating valve and pressure gage may cause very little, if any, pressure increase on the gage. You can best determine if a bearing is receiving oil by inspecting it occasionally, just after engine shut-down. There should be plenty of oil in the vicinity of the parts being lubricated. Another method for checking bearing lubrication is to note the temperature of the bearings by feeling them with the hand after engine shut-down. You should be able to keep your hand on them for at least a few seconds.

You can help prevent most oil line stoppage by observing the following rules:

1. Never use cotton waste or paper towels for cleaning an engine. They may leave lint or small bits of material which later may collect in the lines.

2. Service the oil filters at specified intervals. Clean the case properly and when the lines are removed, blow them out with compressed air.

FUEL INJECTION EQUIPMENT AND CONTROLS

The fuel system is one of the most complicated of all engine systems; therefore, special care must be exercised when making adjustments and repairs. Even though manufacturers have designed many different fuel systems, the basic principle involved is the same in all of them. If you understand the basic principle for one system, you will have no difficulty in becoming familiar with other systems. The procedures for the maintenance and repair of the various systems are also similar.

Let's review briefly not only the function of a fuel system but also the various types of fuel systems. As you know the function of a fuel injection system is to deliver fuel to the engine cylinders under specific conditions: at a high pressure, at the proper time, in the proper quantities, and properly atomized. This function may be carried out by either one of two types of systems: the air injection type or the solid injection type. Since there are few air injections systems now in use, we will consider only the solid (mechanical) injection type systems.

Solid injection systems may be classified as jerk pump systems and common rail systems. Variations are to be found in each of these systems. The following examples show some of the basic differences between the various solid injection systems.

Systems of the JERK PUMP type may be identified as either individual pump systems or unit injection systems. Some jerk pump systems use a separate pump and fuel injector for each cylinder, while the unit injection systems combine the pump and injector into a single unit.

The Bosch system is an example of an individual pump system. The pump is a cam-actuated, constant stroke, lapped plunger and barrel pump. The pump times, meters, distributes, and provides the necessary pressure to inject the fuel into the cylinder through a separate nozzle.

The General Motors unit injector is an example of a unit injection system. It embodies a cam-actuated, constant stroke, lapped plunger and bushing, a high pressure pump, and an injection nozzle, all in one unit.

In the Cummins injection system, a cam-actuated injector and nozzle assembly is mounted in each cylinder. This system employs a common metering device that distributes a measured quantity of fuel to each of the injectors. The Cummings injection system embodies characteristics of the unit injector and is sometimes classified as such, although it is also called a distributor system.

The Fairbanks-Morse injection system is another example of a jerk pump system.

The injection system known as the COMMON RAIL system includes two types: the basic

common rail system and the modified common rail system.

The fuel injection systems used on Atlas engines and some older models of Cooper-Bessemer engines are of the basic type. In this system one untimed, high-pressure pump supplies fuel at injection pressure to a main header (common rail). The fuel flows from the header to the injector valves and nozzles at each cylinder. The injector valves are cam-operated and timed. Metering of the fuel is controlled by the length of time the nozzle remains open and by the pressure maintained by the high-pressure pump in the common rail.

The modified common rail system (constant pressure), found on newer models of Cooper-Bessemer engines, uses a high-pressure pump to maintain fuel at the injection pressure in an accumulator bottle. The fuel is metered by individual valves mounted on the side of the engine; it then flows to the pressure-operated nozzles in the cylinder head, to be atomized and distributed in the cylinder.

Since complete details for the maintenance and repair of each of the various fuel systems in service are beyond the scope of this book, specific information on a particular fuel injection system must come from the appropriate manufacturer's technical manual.

FUEL INJECTION PUMPS AND INJECTORS

In any discussion of a fuel system, the importance of each of its parts cannot be overlooked. The first requirement for trouble-free operation of a fuel system is clean fuel. Accordingly, the filters, the strainers, the tanks, the transfer pumps, and the lines must be maintained according to prescribed instructions. Even when these parts function properly, the principal elements of the injection system—pressure pump, injection valves, and injection nozzles—are subject to troubles. The following discussion covers some of these troubles, their symptoms and causes, and provides general information concerning maintenance and repair of this equipment. As you study this information, keep in mind the differences which may exist between the various systems. (A system, for example, may be of the jerk pump or common rail type, or the pressure pump and the injector may be separate or combined.)

Damaged Plunger

In the plunger and barrel assembly of a high-pressure pump and in the plunger and bushing assembly of a unit injector, the symptoms and causes of damage are similar.

Damage may become apparent through erratic engine operation. Symptoms vary widely and may include failure of the engine to develop full power, low exhaust temperature, low firing pressure for the affected cylinder, difficulty in balancing (calibrating) the pumps or injectors, and failure of one or more cylinders of the engine to fire. Damage to a plunger and the part in which it slides may also be recognized by testing the unit on a test stand. However, the best way to determine the extent of damage is to disassemble the unit, clean it thoroughly, and then carefully inspect each part.

Cleaning of the units can be best accomplished by use of an approved solvent. Clean diesel fuel may be used when more effective cleaners are not available. A brush must be used with diesel fuel and even then, removal of gummy deposits is difficult. Keep each plunger and barrel (bushing) together during the inspection to avoid improper assembly, as they are manufactured in matched sets.

The use of a magnifying glass during the examination of a plunger will facilitate the detection of damage. Inspect for fine scratches, dull surface appearance, cracks, pit marks (usually accompanied by dark discoloration), and erosion and roughness at the edge of the helix or at the end of the plunger. An example of a badly scored plunger is illustrated in A of figure 3-14. A plunger with the lapped surface and helix edge in good condition is shown in B of figure 3-14. Surface irregularities in the region illustrated are serious because they affect metering and, consequently, engine operation.

When examining a barrel or bushing, search for erosion of the ports or scoring of the lapped surfaces. Pay particular attention to the lapped plane surface at the end of a pump barrel. Rust or pit marks on this surface must be removed by lapping before reassembly.
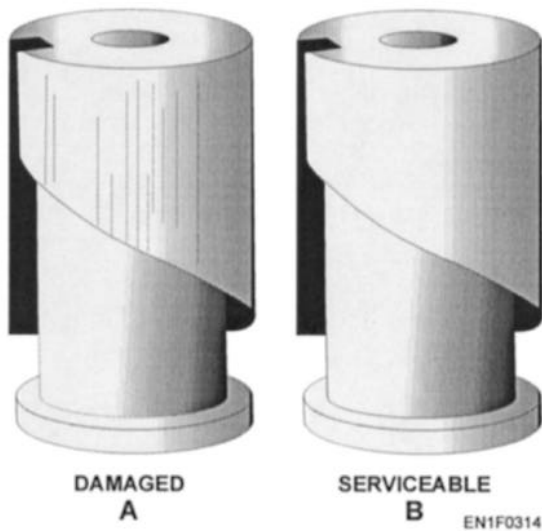
Figure 3-14.—A damaged and serviceable plunger.

Damage to the plunger of a fuel injection pump or injector may be caused by such different factors as entry of dirt into the equipment, careless handling while the equipment is disassembled, corrosion, and improper assembly and disassembly procedures.

Dirt and water are responsible for practically all trouble encountered with fuel injection equipment. If the units are not properly protected, they can be damaged beyond repair within a very short period of operation. Remember that the clearances between the lapped surfaces are so small that occasionally extremely fine particles, such as dust from the atmosphere, are capable of scoring these surfaces. Then small amounts of water that may collect from condensation will corrode these surfaces.

An engine should never be operated unless the fuel has been properly filtered before reaching the injection equipment. Although regular filters and strainers are present in all fuel systems, in some systems special safety filters or screens are incorporated to further reduce the possibility of foreign matter mixing with the fuel as it reaches the pump and the injector. The location of these additional safety devices depends upon the system. In one system a screen is placed between the fuel transfer pump and the fuel distributor, while in another a filter is mounted directly on the pump.

During the overhaul of fuel injection equipment, a spotlessly clean working space is essential for the protection of all parts. Ideally, the area should also be air conditioned. All air should be thoroughly filtered before it enters the space. Benches should have smooth tops. Metal-topped benches should be covered with linoleum or lint-free rags. Ample quantities of approved cleaning solvent, of clean fuel oil, and of compressed air to blow parts dry, should be used to help ensure cleanliness during overhaul. Never use rags or waste to clean injectors, as lint particles from them may damage the injector parts.

From the time a unit is removed from the engine until it is replaced on the engine, extreme care must be exerted to keep dust and dirt away from all its parts. Before any connections are loosened, all dirt should be removed from the unit, tubing, and fittings by washing. After removal of the unit from the engine, all opening (pump, nozzle, tubing, or injectors) should be covered with approved caps or coverings.

Because many surfaces of the parts of pumps and injectors are lapped to extremely accurate finishes, it is essential that they be HANDLED WITH GREAT CARE. Parts that are dropped may be bent, nicked, dented, or otherwise ruined. All work should be done well over the center of the bench. The use of a linoleum covering will reduce casualties caused by dropping parts on the bench. Never leave parts uncovered on the bench, but keep them immersed in diesel fuel until handled. Never handle lapped surfaces when they are dry, as the perspiration on your hands may cause corrosion. Before a lapped surface is handled, it should be immersed in clean diesel fuel, and the hands rinsed in clean fuel. Since the mating parts of pumps and injectors are fitted to one another, such parts as plunger and barrel should be kept together to avoid interchanging.

Since water in the fuel, or improper storage of parts, can also cause CORROSION of the parts of a pump or an injector, all fuel should be centrifuged, and filter and strainer cases drained periodically to prevent excessive collection of water. Information on proper stowage procedures should be obtained from the appropriate technical manual.

Special care must be exercised in DISASSEMBLING and ASSEMBLING the parts of a fuel injection system, since any damage to these finely finished surfaces will necessitate replacement of the parts. When work is being done on any part of a fuel injection system, the procedure outlined in the engine technical manual, or the manufacturer's fuel system technical manual, must be followed.

Remember that the damage to a plunger and barrel assembly of a fuel pressure pump or to the plunger and bushing assembly of a unit injector generally requires replacement of the parts. A damaged part may not be replaced individually. A plunger and its mating part (barrel, bushing, or bore) must be installed as a complete assembly.

External Leakage

Trouble caused by external leakage from an injection pump or an injector may become sufficiently serious to cause an engine to misfire. It is of extreme importance that signs of external leakage be detected as soon as possible. Leakage outside of the combustion space may be sufficiently large not only to affect engine operation but also to create a fire hazard. External leakage of a unit injector can cause fuel dilution of the engine lube oil, reduce lubrication, and increase the possibility of a crankcase explosion.

In general, external leakage from pumps and injectors is caused by improper assembly, loose connections, faulty gaskets, damaged threads and sealing surfaces, broken springs, or cracked housings or bodies. While leakage from pumps is generally visible during engine operation, leakage from an injector may not become apparent until appropriate tests are performed.

You can stop the external leakage from a pump or injector either by tightening loose connections or by replacing the damaged parts. Before the equipment is inspected for leakage, thoroughly clean all parts. On some equipment, you may eliminate mild roughness or discoloration of the sealing surfaces by lapping.

Stuck Plunger

When the cylinder of an engine fails to fire, it is an indication that the injection pump plunger is stuck. Misfiring may occur intermittently if the plunger sticks and releases at intervals. Upon disassembly, it may be difficult to remove the plunger. Sometimes the plunger may stick when the pump or the injector is assembled, but will work smoothly when the unit is disassembled. At times, the plunger will not stick until some time after the unit has been removed from the engine. This is particularly true when the plunger and mating part have been stored under conditions that cause corrosion, or when the parts have been mishandled after removal.

A unit injector may be checked, after removal from the engine, by performing the binding plunger test. This test is performed by depressing the plunger, either by hand or by using the "popping" fixture of a test stand, and noting the return action of the plunger. The plunger should return with a definite snap. This test should be performed at three successive rack settings. A sluggish return action indicates a sticky plunger.

A sticking plunger may be caused by dirt, gummy deposits in the unit, or distortion of the plunger and its adjacent part.

The movement of a plunger may be restricted or entirely prevented by small particles of dirt which may lodge between the plunger and its mating surface. Lacquer-like deposits, from fuel, will also interfere with the movement of the plunger.

The greatest care must be taken when handling the parts of a pump or injector. Because of the extremely close clearances between plunger and mating surfaces, a slight distortion of either will cause binding. Distortion may result from dropping, from striking the plunger and a mating part, or from improper assembly.

Stuck plungers in fuel pumps or injectors should be freed or replaced. Sometimes a little cleaning may eliminate the need for a replacement. The plunger and barrel or bushing assembly should be soaked in an approved cleaning fluid. The assembly should be soaked overnight, or longer if necessary. Cleaning fluids approved for this purpose will immediately soften and remove any paint or enamel with which they come in contact. These fluids should be used with care, since they will damage rubber gaskets.

The specific procedures for cleaning fuel injection equipment, although similar, vary to some degree, depending upon the unit involved

and the manufacturer. The following brief description of the procedures for equipment made by two different manufacturers emphasizes some of these similarities, and further emphasizes the need for following only the procedures indicated in the appropriate manufacturer's technical manual.

A plunger of a Bosch fuel injection pump can be loosened by cleaning. However, if the plunger does not slide freely in the barrel, both the plunger and barrel should be cleaned with an approved cleaning fluid, rinsed in clean fuel oil, and blown dry with compressed air. A small quantity of mutton tallow should then be placed on the plunger. Working the plunger back and forth and rotating it in the barrel should remove all gummy deposits. Instructions for Bosch fuel injection equipment state that such items as hard or sharp tools or abrasives of any kind should never be used in cleaning the pumps.

Freeing the sticking plunger in a GM unit injector may be done in much the same manner as in a Bosch pump.

Stains on plungers may be removed by the use of a limited quantity of jewelers' rouge on a piece of soft tissue paper. It is important to remember that the plunger should not be lapped to the bushing with an abrasive such as jewelers' rouge. After a plunger has been cleaned with jewelers' rouge, it must be cleaned thoroughly with diesel fuel before being placed in the bushing. If after repeated cleanings, the plunger still does not slide freely, you may assume that either the plunger or the bushing is distorted.

The principal difference in the cleaning procedures for these two units of equipment is in the use of abrasives. If the recommended cleaning procedure for these units fails to loosen the plunger so it will slide freely, the plunger and its mating part will have to be replaced.

Broken Plunger Spring

A pump of an injector will fail when the plunger spring breaks and fails to return the plunger after injection has occurred.

Factors which contribute to broken plunger springs are failure to inspect the springs thoroughly and careless handling.

Broken plunger springs must be replaced. Also they should be replaced when there is evidence of cracking, chipping, nicking, weakening of the spring, excessive wear, or when the condition of the spring is doubtful.

Jammed Fuel Control Rack

If an engine is to operate satisfactorily, the fuel control rack must be completely free to move. Since the rack controls the quantity of fuel injected per stroke, any resistance to motion will result in governing difficulties. When this occurs, the engine speed may fluctuate (decreasing as the engine is loaded; racing as the load is removed), or the engine may hunt continuously or only when the load is changed. If the fuel control rack becomes jammed, it may become impossible to control the engine speed with the throttle. The engine may even resist securing efforts under such conditions. Since a sticking fuel control rack can cause serious difficulty, especially in an emergency, every effort should be made to prevent its occurrence. The best way to check for a sticking fuel control rack is to disconnect the linkage to the governor and attempt to move the rack by hand. There should be no resistance to movement of the rack when all springs and linkages are disconnected.

A fuel control rack may stick or jam as a result of a stuck plunger, dirt or paint in the rack mechanism, a damaged rack or gear, or improper assembly. When this jamming or sticking occurs, it is necessary to determine the cause of binding. If it is due to damage, the damaged parts must be replaced; if the stickiness is due to the presence of dirt, a thorough cleaning of all parts will probably correct the trouble. Avoid errors in reassembly and adjustment by carefully studying the instructions.

Backlash in the Control Rack

Backlash, looseness, or play in the fuel control rack, like sticking or binding of the rack, will influence governing of the engine. Proper governing is based on the theory that for every change in speed of the engine, there will be a corresponding change in the quantity of fuel injected.

This is impossible if backlash, looseness, or play exists in the control system. Continuous or intermittent movement of the rack may indicate excessive looseness. Engine speed variations are also indicative of this problem. Note that even though these symptoms are characteristic of a loose rack, a governor which is dirty or out of adjustment will present similar symptoms.

Backlash in a fuel control system is generally due to a wornout gear, rack, or control sleeve. When you disassemble a pump or injector for overhaul be sure to inspect all parts of the control system for signs of excessive wear. If the rack may be moved more than a prescribed amount without moving the plunger, find the parts that are worn, and replace them.

Improper Calibration

When improper calibration (balance) of fuel injector pumps or injectors occurs, there is a difference in the amount of fuel injected into each of the cylinders. If some pumps or injectors deliver more fuel per stroke than others, the engine will be UNBALANCED; that is, some cylinders will carry a greater load than others. This condition may be detected by differences in cylinder exhaust temperatures and firing pressures, and by smoky exhaust from the overloaded cylinders. Roughness in operation and engine vibration are also indicators of an unbalanced condition.

It is important to remember that many other types of engine difficulties may cause engine symptoms identical with those due to unbalance. So when unbalance is suspected, consider first a few of the other faults that may be present such as poor condition of piston rings, inaccurate exhaust pyrometers and thermocouples, mistimed or faulty engine exhaust or inlet valves.

Improper Timing

Improper timing of a fuel system will result in uneven operation or vibration of the engine. Early timing may cause the engine to detonate and lose power. Cylinders which are timed early may show low exhaust temperatures. Late timing usually causes overheating, high exhaust temperatures, loss of power, and smoky exhaust.

Although, usually, improper fuel injection timing is caused by failure to follow the manufacturer's instructions for timing, there may be other causes for the difficulty, depending upon design of the particular systems. For example, fuel injection time in the injection pump of a Bosch system may get out of time because of a worn pump camshaft. The same problem may occur when the adjusting screw on the injector control rack of a GM system becomes loose. Either of these conditions will change fuel injection timing.

Faulty calibration and improper timing are generally due to failure to follow instructions given in the engine technical manual and the fuel injection equipment maintenance manual. These manuals should always be consulted and followed whenever timing or calibration difficulties arise.

GOVERNORS

To control an engine means to keep it running at a desired speed, either in accordance with, or regardless of, the changes in the load carried by the engine. The degree of control required depends on two factors: The engine's performance characteristics and the type of load which it drives. In diesel engines the speed and power output of the engine is determined by varying the amount of fuel that is injected into the cylinders to control combustion. There are two principal types of governors: hydraulic and mechanical.

Hydraulic Governors

It is beyond the scope of this training manual to list all of the possible troubles which may be encountered with a hydraulic governor. This section deals only with the most common ones. Poor regulation of speed may be due to the faulty adjustment of the governor or to faulty action of an engine, a generator, a synchronizing motor, a voltage regulator, or any piece of equipment which has a direct bearing on the operation of the engine.

Manufacturers state that 50% of all governor troubles are caused by dirty oil. For this reason,

Table 3-1.—Troubleshooting Chart-Governor

Trouble	Probable Cause	Corrective Action
Engine hunts or surges	Compensating needle valve adjustment incorrect	Make needle valve adjustment; ensure that the opposite needle valve is closed
	Dirty oil in governor	Drain oil; flush governor; refill
	Low oil level	Fill to correct level with clean oil
	Foamy oil in governor	Drain oil; refill
	Lost motion in engine governor linkage or fuel pumps	Repair linkage and realign pumps
	Governor worn or incorrectly adjusted	Remove governor and make internal checks for clearances according to applicable instructions
	Engine misfiring	Test and replace injectors
	External fuel linkage sticking or binding	Disconnect fuel rack from governor and manually move linkage and progressively disconnect fuel pump links until binding area is found (dirt, paint, and misalignment are the usual causes of binding)
Governor rod end jiggles	Rough engine drive	Check alignment of gears; inspect for rough gear teeth; check backlash of gear
	Governor base not bolted down evenly	Loosen bolts; realign and secure

every precaution should be taken to prevent the oil from becoming contaminated. Most hydraulic governors use the same type of oil that is used in the engine crankcase, provided it is absolutely clean and does not foam. You should change the oil in the governor at regular intervals, depending upon the type of operation, and at least every six months regardless of the operation. You must ensure that the containers used to fill the governors with oil are clean, and that only clean, new, or filtered oil is being used. You should also check the oil level frequently to ensure the proper level is maintained and that the oil does not foam. Foaming of the oil is usually an indication that water is present in the oil. Water in the oil will cause serious damage to the governor. After installing a new governor or one that has been overhauled, adjust the governor compensating

needle valve even though it has previously been done at the factory or repair facility. This adjustment must be made with the governor installed and controlling an engine with a load. If this is not done, high overspeeds and low underspeeds after load changes will result and the return to normal speeds will be slowed. Maintenance and repair of each unit must be in accordance with the manufacturer's maintenance manual and the PMS.

NOTE: When governor troubles are suspected, before performing any maintenance or adjustments, always disconnect the governor fuel rod end from the fuel control rack and ensure that there is no sticking or binding of the rack. This procedure is necessary to determine if the trouble is actually in the governor.

The chart in table 3-1 lists some of the probable causes of trouble which are common to most hydraulic governors. This chart should be used for training purposes only; it must NOT be used to troubleshoot a governor. Always use the applicable manufacturer's instruction manual for troubleshooting. Following are the definitions of the terms used in the chart.

HUNT: A rhythmic variation of speed which can be eliminated by blocking the fuel linkage manually, but which will reappear when returned to governor control.

SURGE: A rhythmic variation of speed always of large magnitude which can be eliminated by blocking the fuel linkage and which will not reappear when returned to governor control unless the speed adjustment of the load changes.

JIGGLE: A high frequency vibration of the governor fuel rod end or engine linkage. Do not confuse jiggle with normal regulating action of the governor.

Mechanical Governors

Mechanical governors used in the Navy are generally of the spring-loaded flyball type. All mechanical governors have a speed droop. This means that as the load is increased at a constant throttle setting, the speed of the engine will drop or droop slightly, rather than remain constant. Consequently, mechanical governors are never used where absolute constant speeds are necessary.

There are several types of mechanical governors. Two of the most common types are used on GM 71 engines. One type, known as the constant-speed governor, is used on generator sets and is designed to hold the speed of the engine at a predetermined operating speed. The other type is similar in construction and is used primarily for propulsion engines. It has a throttle plate so designed that speeds intermediate between idling and full speeds may be obtained by manual adjustment. The following description applies to both types of governors. Do note, however, that on the constant-speed governor, there is no buffer spring adjustment.

In the idling speed range, control is effected by centrifugal force of two sets of flyweights (figure 3-15), large and small, acting against a light
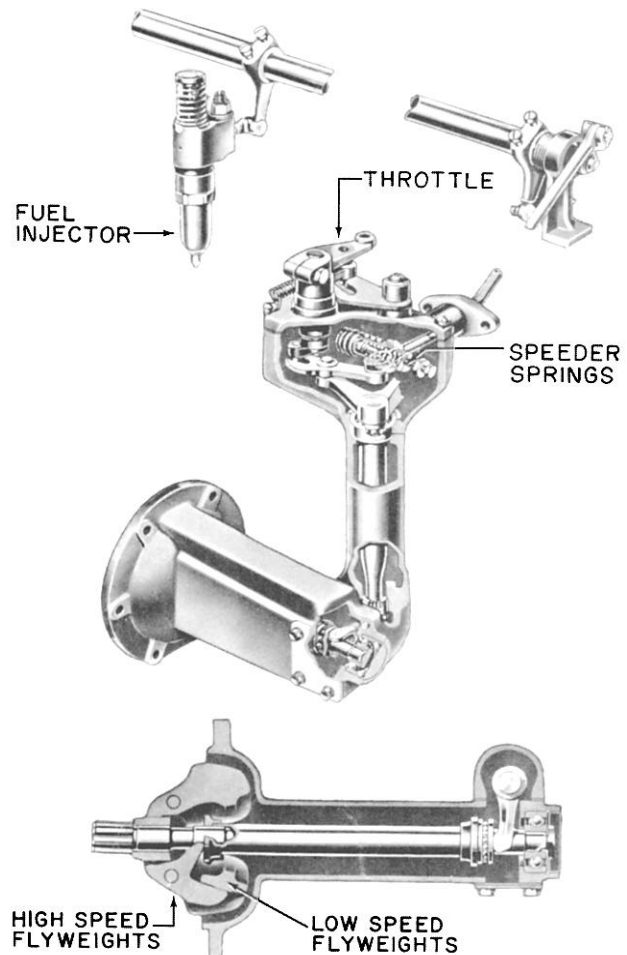

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Figure 3-15.—GM mechanical governor.

(low speed) spring. Maximum speed control is effected by the action of the high speed (small) flyweights acting against a heavy (high speed) spring. (See figure 3-16.)

Mechanical governor faults usually manifest themselves in speed variations; however, not all speed variations indicate governor faults. When improper speed variations appear do the following:

1. Check the load to be sure that speed changes are not the result of load fluctuations.

2. If the load is found to be steady, check the engine to be sure all cylinders are firing properly.

3. Make sure there is no binding in the governor mechanism or operating linkage between governor and engine, and that no binding exists in the injector control rack shaft or its mounting brackets. If you find no binding anywhere and the governor still fails to control the engine properly, you may assume the governor is worn or unfit for further service until the unit has been completely disassembled, inspected, and rebuilt or replaced.
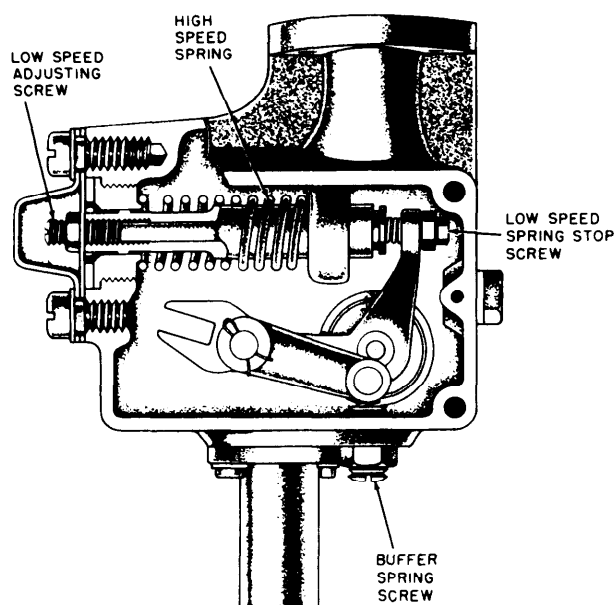
121.23

Figure 3-16.—Mechanical governor control mechanism.

Adjustment procedures for the replacement of any governor are listed in the manufacturer's instruction manual and should be followed with particular attention given to the precautions listed.

OVERSPEED SAFETY DEVICES

Mechanical overspeed trips depend on the centrifugal forces developed by the engine and should be maintained in good working condition. A faulty overspeed device can endanger not only the engine but also personnel if the engine explodes or flies apart because of uncontrolled speed.

The engine instruction manual contains information as to the speed at which the overspeed is supposed to function. Most overspeed trips are adjustable. Prior to making any change in the adjustment of the overspeed trip, determine if the engine did not trip out for some reason other than the action of the element of the overspeed trip. It is highly advisable that you first check the accuracy of the tachometer and then test the overspeed trip. All spring tension adjustments and linkage adjustments to an overspeed trip are critical. Instructions given for making these adjustments are found in the manufacturer's instructions manual and must be followed.

Hydraulic overspeed trips are extremely sensitive to dirt. Dirt or lacquer-like deposits may cause a trip to bind internally. The speed sensitive element must be kept clean and so should all parts of the linkage and mechanisms incorporated in this speed sensitive element. When painting around the engine, the painter should be cautioned against allowing paint to fall on joints, springs, pins, and other critical points in the linkage.

All linkage binding should be eliminated. If parts are bent, badly worn, improperly installed, dirty, or if their motion is restricted by some other part of the engine, the trip will not function properly. On occasion the drive shaft of the overspeed trip may be broken and prevent rotation of the flyweight and the overspeed trip. Insufficient oil in the hydraulic trip may be another source of this problem. Oil should be maintained at the level specified in the instruction manual.

The cause of any malfunction should be determined and eliminated. This will involve cleaning the trip and its linkage, removing the source of

binding, replacing faulty parts, adding oil to hydraulic type trips, or adjusting the speed sensitive element, always in accordance with the instruction manual. If the trip has been damaged, it is advisable to install a spare overspeed trip and completely rebuild or overhaul the damaged one.

REPAIR OF INTERNAL COMBUSTION ENGINES

The Navy uses so many models of diesel engines that it is not possible to describe in any detail all the overhaul procedures used by the Navy. Detailed repair procedures are listed in the manufacturers' technical manuals and in your PMS. Always consult the manuals and the maintenance requirement cards (MRCs) before starting any type of repair work. Pay particular attention to installation tolerances, wear limits, adjustments, and safety procedures. Also be sure to follow the general rules, listed below, which apply to all engines.

1. Observe the highest degree of cleanliness in handling engine parts. Engines have been completely wrecked by the presence of abrasives and various objects which have been carelessly left in the engines after overhaul. Make sure that any engine assembled for post-repair running is scrupulously free of foreign matter prior to running. Too much emphasis cannot be given to the necessity for maintaining engines clean both internally and externally. Since dirt entering the engine during overhaul causes increased wear and poor operation, it is essential that all repair work be done under clean conditions. When overhaul or repair of precision parts and surfaces is required, the parts and the surface should be thoroughly cleaned and wrapped in a clean cloth or suitable paper. The parts should then be stored in a dry place until reinstalled. During installation, parts should be wiped with a cloth free of lint and coated, where applicable, with clean lubricating oil. When removing or installing parts such as pistons, connecting rods, camshafts, and cylinder liners, make sure that these parts are not nicked or distorted. Take precautions to keep dirt and other foreign material in the surrounding atmosphere from entering the engine while it is being overhauled. As an example, during shipyard overhaul periods the engine should be protected when sandblasting is occurring in areas adjacent to the ship.

2. Before starting repair work, make sure that all required tools and spare parts are available. Plan ahead for repair periods so everything needed is available to ensure successful and expeditious completion of the work.

WARNING

Never attempt to jack the engine over by hand without first disabling the starter circuit.

3. Disable the starter circuit and tagout the starter before you start working, particularly when the jacking gear is to be engaged.

4. Keep detailed records of repairs, including measurements of worn parts (with hours in use), and the new parts installed. Later, an analysis of these records will indicate the number of hours of operation that may be expected from the various parts and will facilitate prediction as to when they should be renewed before a failure occurs. Measurement of new parts are needed to determine whether or not they come within the tolerances listed in the manufacturers' instruction books or the wear limit charts. In addition, before installation, all replacement parts should be compared with removed parts to ensure that they are suitable.

5. Do not test an overhauled diesel engine at 125% of full load or any other overload before the engine is returned to service. It has been reported that some overhauled diesel engines used for driving generators are being tested at 125% of full load before being returned to service. The original purpose for this test was to demonstrate a 25% overload capability for a 2-hour period to absorb occasional electrical peak loads. The nameplate rating of many of the older generator sets indicates a 25% temporary overload capacity. (More recent generator sets have a single rating with no stated overload requirement.) The earlier practice was a reasonable approach since the engine was frequently capable of substantially greater power than could be absorbed by the generator and the 125% test was not likely to be detrimental to the engine. Now that these engines have aged, the margin of excess power available

is less and the overload test is neither required nor desirable.

Another important point to remember is that if you cannot overhaul an engine due to lack of space, manpower, or expertise, you may request outside help by using an OPNAV Form 4790.2K. This form, when used as a work request, will be sent to a Ship Intermediate Maintenance Activity (SIMA). The SIMA will then accept or reject the work request. If the work request is accepted, the SIMA will order all repair parts, overhaul the engine, and perform an operational test in accordance with manufacturers' technical manuals and *NAVSHIPS Technical Manual,* chapter 233.

As stated earlier in this section, since maintenance cards, manufacturers' maintenance manuals, and various other instructions discuss repair procedures in detail, this chapter will be limited to general information on some of the troubles encountered during overhaul, the causes of such troubles, and the methods of repair.

PISTON ASSEMBLIES AND RODS

Piston assemblies may have the trunk-type or the crosshead-type pistons. The majority of engines in use by the Navy have trunk-type pistons. Since the troubles encountered with crosshead pistons are very similar to those encountered with the trunk type, only the latter is discussed here.

PISTONS

Trunk-type pistons are subject to such forces as gas pressure, side thrust, inertia, and friction. These forces, together with overheating and the presence of foreign matter, may cause such troubles as piston wear, cracks, piston seizure, and piston pin bushing wear (see figure 3-17).

Piston wear is characterized by an excessive clearance between the piston and the cylinder. Symptoms of excessive clearance between a piston and cylinder are piston slap and excessive oil consumption. Piston slap occurs just after top dead center and bottom dead center, as the piston shifts its thrust from one side to the other. As the cylinder taper increases with wear, oil consumption increases. Since taper causes the rings to flex on each stroke of the piston, excessive ring wear

Troubles	Possible Causes
Undue piston wear; crown and land dragging	Insufficient lubrication Improper cooling water temperatures Overload Unbalanced load Improper fit Dirty intake air cleaner Dirty oil Improper starting procedures
Cracks Crown	Faulty cooling Loose piston Obstruction in cylinder Faulty nozzle spray
Lands	Insufficient lubrication Cocked piston Insufficient ring groove clearance Excessive wear of piston ring grooves Broken ring Improper installation or removal
Piston seizure	Inadequate lubrication Excessive temperatures Improper cleaning
Piston pin bushing wear	Insufficient lubrication Excessive temperatures Overload Unbalanced load

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Figure 3-17.-Piston troubles and their causes.

occurs, allowing lubricating oil to pass and be burned in the cylinder. This results in the accumulation of excessive carbon deposits on the piston, the combustion chamber, and the engine exhaust valves or ports. This accumulation of carbon deposits will cause erratic operation and greatly reduce engine efficiency.

Occasionally pistons and liners become sufficiently worn to permit the piston to cock over in

the cylinder. This allows the crown and ring lands to drag on the cylinder wall. The results of dragging can be determined by visually inspecting the parts of the piston in question. However, most of the pistons now in use in the Navy are free from this trouble, since the crown and ring lands are of smaller diameter than the skirt and do not contact the cylinder wall.

Some piston wear is normal in any engine; the amount and rate depends on several controllable factors. The causes of excessive piston wear are also the causes of other piston troubles.

One of the factors controlling wear is lubrication. An adequate supply of oil is essential to provide the film necessary to cushion the piston and other parts within the cylinder and prevent metal-to-metal contact. Inadequate lubrication will not only cause piston wear but the extra friction may also cause piston seizure, land breakage, and piston pin bushing wear.

Lack of lubrication is caused either by a lack of lube oil pressure or by restricted oil passages. The pressure-recording instruments usually give warning of low oil pressure before any great harm occurs. However, clogged passages offer no such warnings. Only by inspecting and cleaning the piston and connecting rod assembly may you insure adequate lubrication.

Another controllable factor that may be directly or indirectly responsible for many piston troubles is improper cooling water temperatures. If an engine is operated at higher than the specified temperature limits, lubrication troubles will develop. High cylinder surface temperatures will reduce the viscosity of the oil. As the cylinder lubricant thins, it will run off the surfaces. The resulting lack of lubrication leads to excessive piston and liner wear. On the other hand, if the engine is operated at temperatures that are below those specified, viscosity will be increased, and the oil will not readily reach the parts requiring lubrication.

Oil plays an important part in the cooling of the piston crown. If the oil flow to the underside of the crown is restricted, deposits caused by oxidation of the oil will accumulate and lower the rate of heat transfer. For this reason, the underside of each piston crown should be thoroughly cleaned whenever pistons are removed.

While insufficient lubrication and uneven cooling may cause ring land failure, excessive oil temperatures may cause piston seizure. An increase in the rate of oxidation of the oil may result in clogged oil passages or damage to piston pin bushings.

Seizure and excessive wear of pistons may be caused by improper fit. New pistons or liners must be installed with the piston-to-cylinder clearances specified in the manufacturer's technical manual. If clearance is insufficient, a piston will NOT wear in and will probably bind. The resulting excess surface temperatures may lead to seizure or breakage.

Binding increases wear and shortens piston life by scuffing the liner or galling the piston skirt. Scuffing roughens the liner so that an abrasive action takes place on the piston skirt, thus generating additional heat which may distort or crack the piston or liner. Galling, especially on aluminum pistons, causes the metal to be wiped in such a manner that the rings bind in the grooves.

A loose fitting piston may be just as destructive as one which is too tight. A loose piston may cause dragging and cocking of the piston, which in turn may cause broken or cracked ring groove lands.

Excessive wear on the piston and piston pin bushing may be caused by either an overload or by an unbalanced load. Overloading an engine increases the forces on the pistons and subjects them to higher temperatures, thus increasing their rate of wear. There should be a load balance on all pistons at all times. Balance of an engine is determined by checking the exhaust gas temperature at each cylinder, the rack settings, and the firing and compression pressures.

Cracking of the lands of a piston is caused by insufficient ring groove clearance. For correct piston ring operation, proper clearance must be maintained between the ring and the land, and also between the ends of the ring. This is necessary in order that the ring may be free to flex at all temperatures of operation. The clearance depends upon the ring and the materials involved.

After installing a ring, check the clearance between the ring and the land. This check is made

Excessive Wear		Sticking	Breakage

A. Symptoms:
  1. Low compression
  2. Hard starting
  3. Loss of power
  4. Smoky exhaust
  5. Waste of fuel
  6. Excess oil consumption
  7. Poor engine operation
	(Other factors which may cause low compression pressure:
	
	a. Leaking cylinder valves
	b. Faulty injector gasket
	c. Faulty head gasket
	d. Leaking after-chamber valves
	e. Clogged intake ports
	f. Intake air header leakage
	g. Faulty blower
	h. Clogged air filter)
	Other factors which may cause excessive oil consumption:
	a. Loose bearings
	b. High lube oil temperatures
	c. Oil line leakage
	d. Improper oil)
		C. Symptoms:
		  1. Low compression
		  2. Loss of power
		  3. Smoky exhaust
		  4. Excessive oil consumption
		  5. Blow-by forcing fumes from crankcase
			E. Symptoms:
			  1. Hard starting
			  2. Loss of power
			  3. Excess oil consumption
			  4. Possible emission of smoke from crankcase breather

B. Causes:
  1. Inadequate lubrication
  2. Excessive piston heat
  3. Rings damaged during installation
  4. Ring- to-land clearance insufficient
  5. Dust or dirt in intake air
  6. Dirt in lube oil or fuel
  7. Rings stuck in grooves
  8. Worn cylinder liners
		D. Causes
		  1. Improper ring-to-land clearance
		  2. Insufficient ring pressure
		  3. Excessive operating temperature
		  4. Improper oil
		  5. Improper installation
			F. Causes:
			  1. Cylinder liner ridge
			  2. Cylinder port damage
			  3. Insufficient gap clearance
			  4. Insufficient clearance behind ring

Figure 3-18.—Piston ring troubles, their symptoms and causes.   121.2

with a thickness gage, and must be made completely around the piston.

Replace most damaged or excessively worn pistons. Since replacement of damaged pistons is usually necessary, shipboard repair parts should always be maintained at full allowance.

PISTON RINGS

The troubles to which piston rings are subject and their symptoms and causes are listed in figure 3-18.

All symptoms and causes shown for ring wear are either directly and indirectly related to

other ring and piston troubles. In addition to symptoms and causes of piston ring troubles, there are other factors that may also be responsible either for low compression or for excessive oil consumption.

When a cylinder with a low compression pressure is located, the possibility of the cause being some factor other than excessive wear should be eliminated before the pistons rings are disassembled or replaced. Look at figure 3-18. Of the causes listed under "Other factors which may cause low compression pressure" are a, b, c, d, and there are causes that would affect the pressure in only one cylinder assembly of a multicylinder engine. Causes f, g, and h may affect a group of cylinders, or possibly all cylinders. Therefore, when symptoms indicate compression ring wear consider first other possibilities. Excessive oil consumption is generally associated with worn oil rings, but there are other factors which may cause abnormal oil usage, and these should be checked before replacement of oil rings is undertaken.

Oxidation of the lube oil leaves carbon deposits on the rings and in the grooves. It is caused by excessive operating temperatures. The carbon buildup limits movement and expansion of the rings, prevents the rings from following the cylinder contour and sealing the cylinder, and may cause sticking, excessive wear, or breakage.

Proper clearance must exist between the ring and land as well as behind the ring, since insufficient ring groove clearance can cause the rings to stick. It is not the function of the rings to support or position the piston in the cylinder bore, but if the proper clearance does not exist, the rings are likely to become loaded by inertia forces and by side thrust on the piston—forces which should be borne solely by the skirt of trunk-type pistons.

Two factors that cause improper ring clearance are:

1. Abnormal amount of carbon deposits on rings and in grooves.
2. Improper dimensions. New rings must have the proper thickness, width, diameter, and gap.

One cause of undue loads on a ring could be insufficient gap clearance. This condition would cause the ring to be forced out and into a port of a ported cylinder, and possibly result in breakage.

A bright spot found on each end of a broken ring indicates insufficient gap clearance. Sufficient gap clearance must exist at both the top and the bottom of the cylinder bore when rings are installed.

Sticking and binding of the ring may result from insufficient ring pressure. The tendency of the ring to return to its original shape pushes it against the cylinder wall, and makes the initial seal. The pressure of the combustion gases behind the rings reinforces this seal. Pressures (compression and combination) within the cylinder force the combustion rings down and cause a seal between the bottom side of the rings and the upper side of the lands; therefore, properly wearing rings will appear shiny on the outer face and bottom side. Any discoloration (usually appearing as black lines) indicates the leakage of gases past the rings. Extended use and overheating may weaken rings to the point where they do not seat properly, and the rings are then likely to bind in the grooves. A check of the free gap for a piston ring will indicate the ring's condition with respect to sealing qualities. If the instruction manual does not give a prescribed dimension for free gap, compare the gap with that of a new ring.

Conditions which cause piston rings to stick in the grooves, wear excessively, or break are often the result of using improper lube oil. Some lube oils cause a resinous gumlike deposit to form on engine parts. Trouble of this nature can be avoided by using Navy-approved oils, or oil recommended by the manufacturer.

Probably the greatest factor affecting the wearing of piston rings is a worn cylinder liner. Therefore, when new rings are installed, surface condition, amount of taper, and out-of-roundness of the liner must all be considered. The ring is in the best position to make allowance for cylinder wear if the ring gaps are in line with the piston bosses. Gaps of adjacent rings should be staggered 180° to reduce gas leakage.

With the wearing away of material near the top of a cylinder liner, a ridge will gradually be formed. When a piston is removed, this ridge must also be removed, even though it has caused no damage to the old set of rings. The new rings will travel higher in the bore by an amount equal to the wear of the old rings, and the replacement of the connecting rod bearing inserts will also increase piston travel. As the top piston ring will strike the ridge because of this increase in travel,

breakage of the ring and perhaps of the land is almost certain if the ridge is not removed.

PISTON PINS AND PIN BEARINGS

Piston pins are made of hardened steel alloy, and their surfaces are precision finished. Piston sleeve bearings or bushings are made of bronze or a similar material. These pins and pin bearings require very little service and total failure seldom occurs.

Wear, pitting, and scoring are the usual troubles encountered with piston pins and piston pin bearings.

Wear of a pin or bearing is normal, but the rate of wear can be unnecessarily increased by such factors as inadequate and improper lubrication, overloading, misalignment of parts, or failure of adjacent parts.

Every time a piston assembly is removed from an engine, the complete assembly should be checked for wear. Piston pins and bushings should be measured with a micrometer to determine if wear is excessive. Do NOT measure areas that do not make contact, such as those between the connecting rod and piston bosses, and the areas under the oil holes and grooves. The correct and limiting values for measurements may be found in the manufacturer's technical manual for the particular engine.

Excessive wear of pins, bushings, or bearings is often the result of insufficient or improper lubrication. (These parts are usually pressure lubricated.) The failure of a pressure lubricating system is usually detected before piston pins, bushings, or bearings are seriously damaged. Insufficient lubrication of these parts is usually caused by obstructions blocking the oil passages of the connecting rods. If the bushings have been installed so that the oil holes do not line up, lubrication may be restricted. Such misalignment of oil holes may also be caused by a bushing coming loose and revolving slightly out of position. Also interchanging the upper and lower connecting rod bearings ON SOME ENGINES may obstruct the flow of oil to the upper end of the rod. Always check the manufacturer's technical manual for information on interchangeability of parts.

If there is misalignment of the connecting rods, uneven loading on piston pins and bearings will result. The fact that a rod is misaligned is usually indicated by uneven wear of the piston pin and bushing and by piston skirt wear. Misalignment may be caused by improper reaming of the bushing for proper clearance.

CONNECTING RODS

Connecting rod troubles usually involve either the connecting rod bearing or the piston pin bearing. Some of these troubles, such as misalignment, defective bolts, cracks, or plugged oil passages, can be avoided by performing proper maintenance and by following instructions in the manufacturer's technical manual.

Misalignment causes binding of the piston, piston pin, and the connecting rod journal bearing. This binding is likely to result in breakage and in increased wear of the parts, leading to total failure and possible damage to the entire engine structure. Connecting rods must be checked for proper alignment before being installed in an engine, and after any derangement involving the piston, cylinder, or crankshaft.

Defective bolts are often the result of over-tightening. Connecting rod bolts should be tightened by using a torque wrench, or an elongated gage to ensure that a predetermined turning force is applied to the nut. Defective threads can cause considerable trouble by allowing the connecting rod to be loosened and cause serious damage to the engine. Whenever rod bolts are removed they should be carefully inspected for stripped or damaged threads and elongation.

Cracked rods are usually the result of overstressing caused by overloading or overspeeding or because defective material was used at the time of manufacture. It is of prime importance to discover the cracks before they have developed to the point where the failure of the rod will take place. No attempts should be made to repair cracked rods. They should be replaced; serious damage may result if breakage occurs during operation.

Restricted oil passages are often the result of improper assembly of the bushing and the connecting rod bearing inserts. They may also be due to foreign matter lodging in the oil passages.

SHAFTS AND BEARINGS

The principal shafts (crankshafts and camshafts) and associated bearings (journal bearings and antifriction bearings) of an internal combustion engine are all subject to several types of trouble. Some of the troubles may be common to all of these parts; others may be related to only one part. Causes of troubles common to all parts are metal fatigue, inadequate lubrication, and operation of the engine at critical speeds.

Metal fatigue in crankshafts, camshafts, and bearings may lead to shaft breakage or bearing failure; however, you must keep in mind that metal fatigue is only one of several possible causes which may lead to such troubles.

Fatigue failure of journal bearings in internal combustion engines is usually caused by cyclic peak loads. Such failures are accelerated by improper or loose fit of the bearing shell in its housing, and by the lack of adequate priming of the lubricating oil system before the engine is started.

Severe overloading or overspeeding of an engine increases fatigue failure. Some indication of the cause of the failure may be obtained by noting which half of a bearing failed. Overloading of the engine will cause failure of the lower halves of main journal bearings, while overspeeding may cause either the upper or the lower halves to fail.

Crankshaft or camshaft failure does not occur too often. When it does occur, it may be due to metal fatigue. Shaft fatigue failure may be caused by improper manufacturing procedures, such as improper quenching or balancing, or by the presence of torsional vibration. Shaft fatigue failures generally develop over a long period of time.

The importance of lubrication cannot be overstressed. Much that has been stated previously about proper lubricants and adequate supply and pressure of lube oils is also applicable to crankshafts, camshafts, and their associated bearings. Some of the troubles which may be caused by improper lubrication are damaged cams and camshaft bearing failure, scored or out-of-round crankshaft journals, and journal bearing failure. Lubrication difficulties you should watch for are low lube oil pressure, high temperatures, and lube oil contamination by water, fuel, and foreign particles.

Operation of an engine at critical torsional speeds and in excess of the rated speed will lead to engine shaft and bearing difficulties. Each multicylinder engine has one or several critical speeds which must be avoided in order to prevent possible breakage of the crankshaft, camshaft, and gear train.

A critical speed of the first order exists when impulses due to combustion occur at the same rate as the natural rate of torsional vibration of the shaft. If the crankshaft receives an impulse from firing at every other natural vibration of the shaft, a critical speed of the second order occurs. Operation at these speeds for any length of time may cause the shaft to break. If critical speeds are not avoided, torsional vibrations may not only cause shaft breakage but may also cause severe damage to the entire gear train assembly.

In some engines, critical speeds fall within the normal operating range; the instruction manual for the specific engine will warn against engine operation for any length of time within the critical speed range. If the critical speed range falls within the normal operating range, it must be conspicuously marked upon the engine tachometer, and every effort should be made to keep the engine from operating in the range. If this is not possible, the critical speed should be passed over as fast as possible.

Overspeeding of an engine must be avoided. If the rated speed is exceeded for any extended period of time, the increase in inertia forces may cause excessive wear of the journal bearings and other engine parts, and in uneven wear of the journals.

CRANKSHAFTS

Scored crankshaft journals are caused not only by lubrication difficulties but also by journal bearing failure or improper and careless handling during overhaul.

Journal bearing failures may cause not only scoring but also broken or bent crankshafts and out-of-round journals. Journal bearing failures may be caused by several different factors and may lead to more than one trouble. The causes and the prevention of such failures are discussed in more detail later in this chapter.

Broken or bent crankshafts may be caused by the improper functioning of a torsional vibration damper. Vibration dampers are mounted on the crankshafts of some engines to reduce the torsional vibrations set up within the crankshaft and to ensure a smoother running engine. If a damper functions improperly, torsional vibrations may rupture the internal structure of the shaft.

The principle of operation is similar in most dampers, yet their construction and their component parts vary somewhat. If the engine is equipped with a vibration damper, the engine instruction manual must be consulted for information on type, construction, and maintenance of the damper.

In most engines, one end of the crankshaft is flanged to receive the damper, the damper being bolted or doweled onto the flange. A damper must be fastened securely to the crankshaft at all times during engine operation; otherwise, the damper will not control the crankshaft vibrations.

Small dampers are usually grease-packed, while larger ones frequently receive lubrication from the main oil system. Dampers that are grease lubricated must have the grease changed periodically, as specified in the manufacturer's instructions. If the assembly is of the elastic type, it must be protected from fuel, lube oil, grease, and excessive heat, all of which are detrimental to the rubber.

Excessive rumbling at certain engine speeds may indicate that the damper is not functioning properly. You must learn to distinguish between this and the normal noise usually heard in some engines during the first and last few revolutions when the engine is starting or stopping. This noise is normal, it is due to the large designed clearances in the damper and is not a sign of impending trouble.

Crankshaft breakage or bending may be the result of excessive bearing clearances. Excessive clearance in one main bearing may place practically all of the load on another main bearing. Flexing of the crankshaft under load may result in fatigue and eventual fracture of the crank web. (See figure 3-19.) Excessive bearing clearance may be caused by the same factors that cause journal bearing failure. Furthermore, off-center and out-of-round journals tend to scrape off bearing material. This leads to excessive wear and to the increase of the clearance between the shaft and
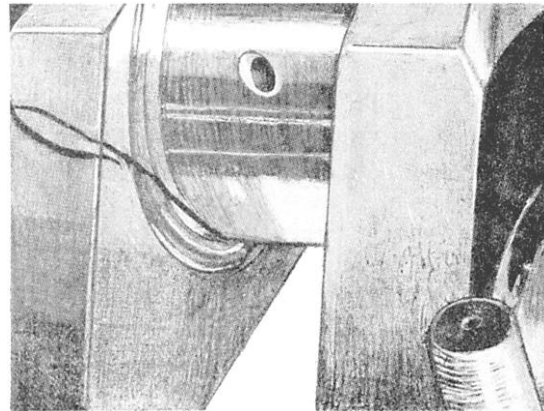

121.3
Figure 3-19.—Cracked crank web.

bearing. You can minimize the possibility of journal out-of-roundness by taking measures to prevent improper lubrication, journal bearing failure, overspeeding or overloading of the engine, excessive crankshaft deflection, and misalignment of parts.

Crankshaft bending breakage (out-of-roundness) may also result from excessive crankshaft deflection. Excessive shaft deflection, caused by improper alignment between the driven unit and the engine, may result in a broken or bent shaft along with considerable other damage to bearings, connecting rods, and other parts. Excessive crankshaft deflection may also be caused by overspeeding an engine. The amount of deflection of a crankshaft may be determined by the use of a straight gage.

The straight gage is merely a dial-reading inside micrometer used to measure the variation in the distance between adjacent crank webs where the engine shaft is barred over. When installing the gage, or indicator, between the webs of a crank throw, place the gage as far as possible from the axis of the crankpin. The ends of the indicator should rest in the prick-punch marks in the crank webs. If these marks are not present, you must make them so that the indicator may be placed in its correct position. Consult the manufacturer's technical manual for the proper location of new marks.

Readings are generally taken at the four crank positions: top dead center, inboard, near or at bottom dead center, and outboard. In some engines, it is possible to take readings at bottom dead center. In others, the connecting rod may interfere, making it necessary to take the reading as near as possible to bottom dead center without having the gage come in contact with the connecting rod. The manufacturer's technical manual for the specific engine provides information concerning the proper position of the crank when readings are to be taken. When the gage is in its lowest position, the dial will be upside down, necessitating the use of a mirror and flashlight to obtain a reading.

Once the indicator has been placed in position for the first deflection reading, do NOT touch the gage until all four readings have been taken and recorded.

Variations in the readings obtained at the four crank positions will indicate distortion of the crank. Distortion may be caused by several factors, such as a bent crankshaft, worn bearings, or improper engine alignment. The maximum allowable deflection can be obtained from the manufacturer's technical manual. If the deflection exceeds the specified limit, take steps to determine the cause of the distortion and to correct the trouble.

Deflection readings are also employed to determine correct alignment between the engine and the generator, or between the engine and the coupling. When alignment is being determined, a set of deflection readings is usually taken at the crank nearest to the generator or the coupling. In aligning an engine and generator, it may be necessary to install new chocks between the generator and its base to bring the deflection within the allowable value. It may also be necessary to shift the generator horizontally to obtain proper alignment. When an engine and a coupling are to be aligned, the coupling must first be correctly aligned with the drive shaft; then, the engine must be properly aligned to the coupling, rather than the coupling aligned to the engine.

CAMSHAFTS

In addition to the camshaft and bearing troubles already mentioned, the cams of a camshaft may be damaged as a result of improper valve tappet adjustment, worn or stuck cam followers, or failure of the camshaft gear.

Cams are likely to be damaged when a loose valve tappet adjustment or a broken tappet screw causes the valve to jam against the cylinder head, and the push rods to jam against their cams. This will result in scoring or breaking of the cams and followers, as well as severe damage to the piston and the cylinder.

Valves must be timed correctly at all times, not only for the proper operation of the engine but also to prevent possible damage to the engine parts. You should inspect frequently the valve actuating linkage during operation to determine if it is operating properly. Such inspections should include taking tappet clearances and adjusting, if necessary; checking for broken, chipped, or improperly seated valve springs; inspecting push rod end fittings for proper seating; and inspecting cam follower surfaces for grooves or scoring.

JOURNAL BEARINGS

Engine journal bearing failure and their causes may vary to some degree, depending upon the type of bearing. The following discussion of the causes of bearing failure applies to most bearings—main bearings as well as crank pin bearings. The most common journal bearing failures may be due to one or to a combination of the following causes:

1. Corrosion of bearing materials caused by chemical action of oxidized lubricating oils. Oxidation of oil may be minimized by changing oil at the designated intervals, and by keeping engine temperatures within recommended limits. Bearing failures due to corrosion may be identified by very small pits covering the surfaces. In most instances, corrosion occurs over small bearings areas in which high localized pressures and temperatures exist. Since the small pits caused by corrosion are so closely spaced that they form channels, the oil film is not continuous and the load-carrying area of the bearing is reduced below the point of safe operation.

2. Surface pitting of bearings due to high localized temperatures that cause the lead to melt.

This is generally the result of very close oil clearances and the use of an oil having a viscosity higher than recommended. Early stages of the loss of lead, due to melting, will be evidenced by very small streaks of lead on the bearing surface.

3. Inadequate bond between the bearing metal and the bearing shell. A poor bond may be caused by fatigue resulting from cyclic loads, or it may be the result of defective manufacturing. A failure due to inadequate bond is shown in figure 3-20. In such failures, the bearing shell shows through the bearing surface clearly.

4. Out-of-round journals due to excessive bearing wear. As the bearings wear, excessive clearance is created; this leads to engine pounding, oil leakage from the bearing, reduced flow of oil to other bearings, and overheating, with the consequent melting of bearing material. To prevent bearing wear, the journals should be checked for out-of-roundness. Manufacturers require crank pins to be reground when the out-of-roundness exceeds a specified amount, but the amount varies with manufacturers. Always check the engine manual for this type of data.

5. Rough spots. Burrs or ridges may cause grooves in the bearings and lead to bearing failure. Removal of rough spots is done with a fine oil stone and a piece of crocus cloth. Be sure to place a clean cloth beneath the journal to catch all particles. Apply a coat of clean lubricating oil to the journal and to the bearing before a bearing is installed.

6. Misalignment of parts. Misalignment of the main bearings can be caused by a warped or bent crankshaft. Such misalignment imposes heavy loads on the main bearings because of the force that is necessary to retain correct alignment between the bearing and the journal.

A bent or misaligned connecting rod can be the cause of a ruined crank-pin bearing. Misalignment between the connecting rod bore and the piston pin bushing bore is indicated by the cracking of the bearing material at the opposite ends of the upper and lower-bearing shell. An indication of a bent connecting rod is heavy wear or scoring on the piston surface.

7. Faulty installation, due to negligence or lack of experience. The paramount factor is inattention to cleanliness. Hard particles lodge between the bearing shell and the connecting rod bore, and create an air space. This space retards the normal flow of heat and causes localized high temperatures. Such condition may be further aggravated if the bearing surface is forced out into the oil clearance spaces and creates a high spot in the bearing surface. The result of a bearing failure is illustrated in figure 3-21. Foreign particles, excessive clearance, or rough surface may cause poor contact between a bearing shell and a connecting rod. Poor contact is indicated by the formation of a gumlike deposit (sometimes referred to as lacquer or varnish) on the back of the shell.

Bearing failures may result from improper fit of the shell to the connecting rod. If the locking lip of a bearing does not fit properly into the recess of the bearing housing, distortion of the shell and failure of the bearing results.
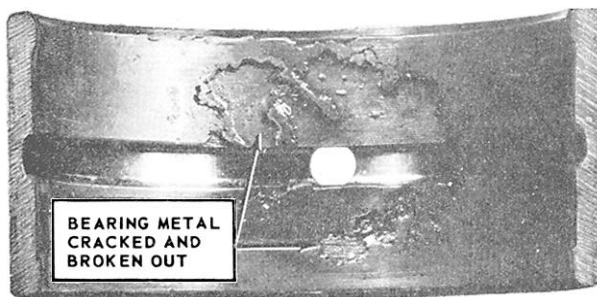
121.4

Figure 3-20.—Bearing failure due to inadequate bond.

121.5

Figure 3-21.—Bearing failure resulting from wiping and excessive temperatures.

Another source of trouble during installation is due to the interchanging of the upper and lower shells. The installation of a plain upper shell in place of a lower shell, which contains an oil groove, completely stops the oil flow and leads to early bearing failure. The resulting damage not only may ruin the bearing but may also extend to other parts, such as the crankshaft connecting rod, piston, and wrist pin.

8. Failure to follow recommended procedures in the care of lubricating oil. Lack of proper amount of lubricating oil will cause the overheating of a bearing, causing its failure (see figure 3-22). In large engines, the volume of the lubricating oil passages is so great that the time required to fill them when starting an engine could be sufficient to permit damage to the bearings. To prevent this, separately driven lubricating oil priming pumps are installed, and by their action, the oil is circulated to the bearings before an engine is started. Priming pumps should be secured prior to starting the engine when the prescribed pressure has been obtained.

Maintenance of recommended oil pressures is essential to ensure an adequate supply of oil at all bearing surfaces. Refer to the oil pressure gage as it is the best source of operational information to indicate satisfactory performance.

Use Navy-approved, low-corrosive lubricating oils at recommended oil temperatures. Recommended temperatures have been determined by extensive tests in laboratory and in service. They are sufficiently high to assure satisfactory

circulation, and sufficiently low to prevent excessive oxidation of the lubricating oil. Normally, the manufacturer's technical manual should be followed as to the correct lubricating oil temperature to maintain. However, if no manual is available, the temperature of the oil leaving the engine should be maintained between 160° and 200°F. When possible, oil must be analyzed at recommended intervals to determine its suitability for further use. In addition, regular service of oil filters and strainers must be maintained, and oil samples must periodically be drawn from the lowest point in the sump to determine the presence of abrasive materials or water. The lube oil purifier should be used in accordance with required procedures. Strict adherence to recommended practices will reduce the failure of bearings and other parts because of the contaminated oil or insufficient supply of clean oil.

FRICTIONLESS BEARINGS

Figure 3-23 lists the troubles that may be encountered with all types of (antifriction frictionless) bearings.

Since dirty bearings will have a very short service life, every possible precaution must be taken to prevent the entry of foreign matter into bearings. Dirt in a bearing which has been improperly or insufficiently cleaned may be detected by noise when the bearing is rotated, by difficulty in rotating, or by visual inspection. Do not discard an antifriction bearing until you have definitely established that something in addition to dirt has caused the trouble. You may determine this by properly cleaning the bearing.

Spalled or pitted rollers or races may be first recognized by the noisy operation of the bearing. Upon removal and after a very thorough cleaning, the bearing will still be noisy when rotated by hand. (Never spin a frictionless bearing with compressed air.) Roughness may indicate spalling at one point on the raceway.

Pay particular attention to the inner surface of the inner race, since it is here that most surface disintegration first occurs. Since pits may be covered with rust, any sign of rust on the rollers or contact surfaces of the races is a probable indication that the bearing is ruined.
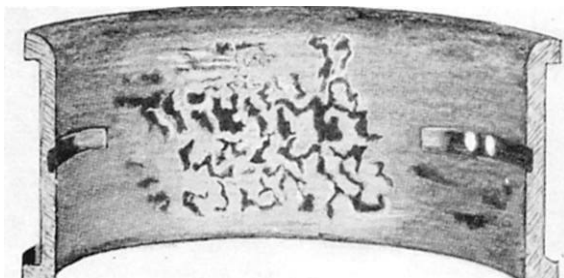

121.6

Figure 3-22.—Overheated bearing.

Trouble	Causes
Dirty bearing	Improper handling or storage Use of dirty or improper lubricant Failure to clean housing Poor condition of seal
Spalled or pitted rollers or races	Dirt in bearing Water in bearing Improper adjustment of tapered roller bearings Bearing misaligned or off square
Dented (brinelled) races	Improper installation or removal Vibration while bearing is inoperative
Failed separator	Initial damage during installation or removal Dirt in the bearing
Races abraded on external surfaces	Locked bearing Improper fit of races
Cracked race	Improper installation or removal (cocking)
Excessive looseness	Abrasives in lubricant

Figure 3-23.—Antifriction bearing troubles and their causes.

Brinelled or dented races are most easily recognized by inspection after a thorough cleaning. Brinelling receives its name from its similarity to the Brinnell hardness test, in which a hardened ball is pressed into the material. The diameter of the indentation is used to indicate the hardness of the material. Bearing races may be brinelled by excessive and undue pressures during installation or removal, or by vibration from other machinery while the bearing is inoperative. If heavy shafts supported by frictionless bearings are allowed to stand motionless for a long time, and if the equipment is subject to considerable vibration, brinelling may occur. This is due to the peening action of the rollers or balls on the races.

Brinelled bearings must not be placed back in service. Steps can be taken to prevent brinelling. Proper maintenance will help a great deal, and the best insurance against brinelling caused by vibration is to rotate the shafts supported by the frictionless bearings at regular intervals (at least once a day) during periods of idleness. These actions will prevent the rollers from resting too long upon the same portion of the races.

Separator failure may become apparent by noisy operation. Inspection of the bearings may reveal loose rivets, failure of a spot weld, or cracking and distortion of the separator. Failure of separators can usually be avoided if proper installation and removal procedure are followed, and steps are taken to exclude the entry of dirt.

Abrasion (scoring, wiping, burnishing) on the external surface of a race indicates that relative motion has occurred between the race and the bearing housing or shaft surface. The race adjacent to the stationary member is usually made a push fit so that some creep will occur. Creep is a very gradual rotation of the race. This extremely slow rotation is desirable as it prevents repeated stressing of the same portion of the stationary race. Wear resulting from the proper creep is negligible and no damaging abrasion occurs. However, abrasion caused by locked bearings or the improper fit of the races must be prevented.

Cracked races will usually be recognized by a definite thump or clicking noise in the bearing during operation. Cleaning and inspection is the best means of determining if cracks exist. Cracks usually form parallel to the axis of the race. The cracking of bearing races seldom occurs if proper installation and removal procedures are followed.

Excessive looseness may occur on rare occasions even though no surface disintegration is apparent. Since many frictionless bearings appear to be loose, even when new, looseness is not always a sign of wear. The best check for excessive looseness is to compare the suspected bearing with a new one.

Wear of bearings, which cause looseness without apparent surface disintegration, is generally caused by the presence of fine abrasives in the lubricant. Taking steps to exclude abrasives and keeping lubricating oil filters and strainers in good condition is the best way to prevent this type of trouble.

Most of the troubles listed in figure 3-23 require the replacement of an antifriction bearing. The cause of damage must be determined and eliminated so that similar damage to the replacement bearing may be prevented.

Dirty bearings may be made serviceable with a proper cleaning, providing other damage does not exist. In some cases, races abraded on the external surfaces can be made serviceable, but it is generally advisable to replace abraded bearings. Dirty frictionless bearings must be thoroughly cleaned before being rotated or inspected.
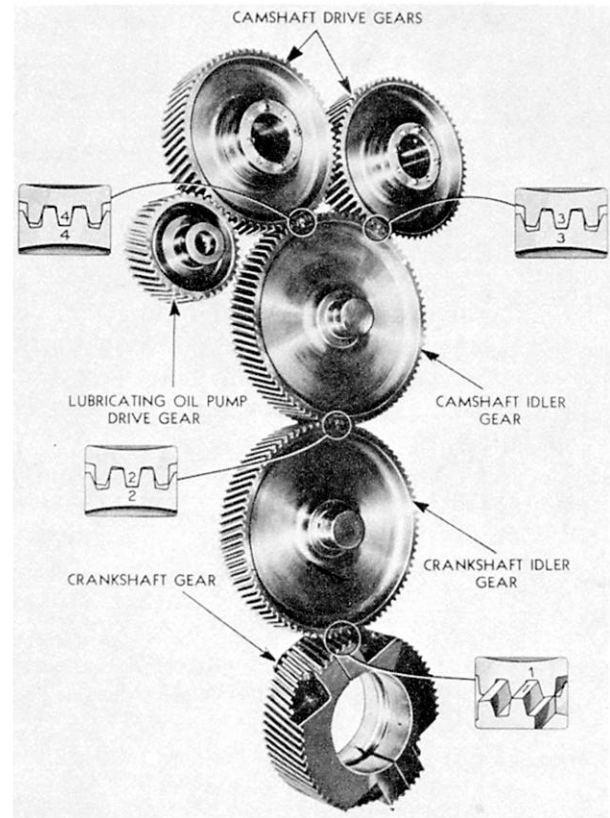
AUXILIARY DRIVE MECHANISMS

Auxiliary drive mechanisms are used in internal combustion engines to maintain a fixed and definite relationship between the rotation of the crankshaft and the camshaft. This is necessary in order that the sequence of events necessary for the correct operation of the engine may be carried out in perfect unison. Timing and the rotation of various auxiliaries (blowers, governor, fuel and lubricating oil pumps, circulating water pumps, overspeed trips, etc.) are accomplished by a gear or chain drive mechanism from the crankshaft. (Some small engine auxiliaries may be belt-driven.)

GEAR MECHANISMS

The principal type of power transmission for timing and accessory drives in most diesel engines is a system of gears similar to those shown in figure 3-24. In some of the larger engines, there may be two separate gear trains, one for driving the camshaft and the other for driving certain accessories.

The type of gear employed for a particular drive depends upon the function it is to perform. Most gear trains use single helical spur gears, while governor drives are usually of the bevel type; reverse and reduction gear units employ double helical gears to balance fore and aft components of tooth pressure.

Small gears are usually made from a single forging, while larger ones are quite often built up in split sections. (See the crankshaft gear in figure

121.8

Figure 3-24.—Relative arrangement of the gears in an auxiliary drive mechanism.

3-24.) Most gears are made of steel, although cast iron, bronze, or fiber are sometimes used.

The timing gear train shown in figure 3-24 is used on some two-stroke cycle diesel engines. The camshafts rotate at the same speed as the crankshaft. Note that two idler gears are necessary to transfer crankshaft rotation to the camshaft gears. The idler gears are used because the camshafts and crankshaft are displaced a considerable distance. If idler gears were not used, the crankshaft and camshaft gears would have to be considerably larger.

A similar timing gear train may be found in some four-stroke cycle engines, except that the camshaft gear or gears will have twice as many teeth as the crankshaft gear to permit the camshaft to rotate at one-half the crankshaft speed.

A different type of drive gear mechanism is used for a four-stroke cycle, V-type gasoline engine. The camshaft gears are driven through a train of bevel gears from the crankshaft. This arrangement serves to drive not only the camshaft but also other accessories, such as a magneto, or distributor, a fuel pump, and a tachometer. An additional gear, called the oil and freshwater pump drive gear, meshes with the crankshaft gear.

The causes of gear failure (improper lubrication, corrosion, misalignment of parts, torsional vibration, excessive backlash, wiped gear bearings and bushing, metal obstructions, and improper manufacturing procedures) are basically the same as the causes of similar troubles in other engine parts. The best method of prevention is to adhere to the prescribed maintenance procedures and follow the instructions given in the manufacturer's technical manual.

Maintenance and repair of gear trains involve a thorough check (for scoring, wearing, pitting, etc.) of the gear shafts, bushings and bearings, and gear teeth during each periodic inspection. Be sure that the oil passages are clear, and that the woodruff keys, dowel pins, and other locking devices are secured to a tight fit in order to prevent longitudinal gear movement. It is essential that all broken or chipped parts be removed from the lubrication system before new gears are installed.

An engine must not be barred over while the camshaft actuating gears are removed from the train. Should the engine be barred over, there is
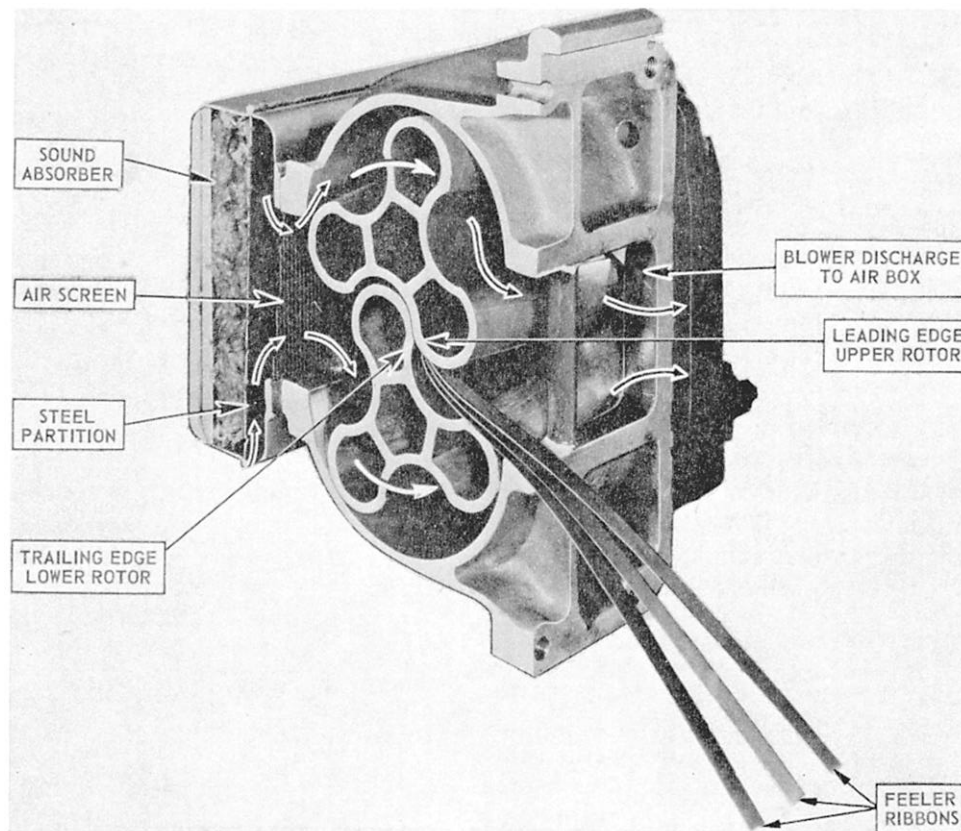

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Figure 3-25.—Checking clearance of positive displacement blower lobes.

danger that the piston will strike valves that may be open and extending into the cylinder. Make certain that any gears removed are replaced in the original position. Special punch marks, or numbers (figure 3-24), are usually found on gear teeth that should mate. If they are not present, make identifying marks to facilitate the correct mating of the gears later.

Bearing, bushing, and gear clearances must be properly maintained. If bushing clearances exceed the allowable value, the bushings must be renewed. The allowable values for backlash and bushing clearances should be obtained from the instruction manual for the engine involved.

Usually, a broken or chipped gear must be replaced. Care should be exercised in determining whether a pitted gear should be replaced.
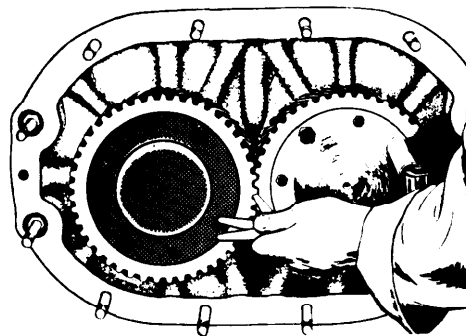
BLOWER ROTOR GEARS

One of the most important parts of a root type blower is the set of gears that drive and synchronize the two rotors. Satisfactory operation depends on the condition of these gears.

Worn gears are found by measuring the backlash of the gear set. Gears with a greater backlash than specified in the applicable technical manual are considered to be excessively worn and, if not replaced, will eventually cause extensive damage to the entire blower assembly.

A certain amount of gear wear is to be expected, but scored and otherwise damaged rotor lobes resulting from excessively worn gears are inexcusable. It is the duty of the engineering force to inspect the gears and lobes, and to measure the clearance at frequent intervals. During the inspection, it will be possible to measure accurately the values of backlash. These values should be recorded. By observing the rate of increase of wear, it will be possible to estimate the life of the gears and to determine when it will be necessary to replace them.

Lobe clearance can be found by determining the difference of the maximum and minimum rotor lobe clearance at the same distance from the center. To find the maximum clearance, hold the rotors so that there is maximum clearance between the two rotor lobes. Then, with feeler gages determine the value of the rotor lobe clearance. (See figure 3-25.)

121.9
Figure 3-26.—Checking the backlash of blower rotor gears.

The minimum clearance is found in a similar manner except that rotor lobes are held in such a position as to take up all slack and backlash. The difference of the two clearance readings is the value of the backlash of the rotor lobes. Since a change in lobe clearance is normally caused by wear of the gears, the gear clearance must be checked. The most direct method for checking gear clearance is by the use of feeler gages. (See figure 3-26.)

Any gear set which has excessive lash or shows any sign of fracture must be replaced with a new set. Since blower drive gears come in matched sets, gears from different sets must not be interchanged.

CHAIN MECHANISMS

In some engines, chains are not only used to drive camshafts and auxiliaries but also to drive such parts as rotating supercharger valves. Connecting links for two types of chains are shown in figure 3-27. Note that the connecting pins in one are secured by cotter pins, while the joint pins shown in the other are riveted.

The principal causes of drive chain failure are improper chain tension, lack of lubrication, sheared cotter pins or improperly riveted joint pins, and misalignment of parts, especially idler gears.

Chain drives should be checked for any symptoms of such difficulties, in accordance with the instructions in the appropriate engine manual. The tension should be adjusted as required during
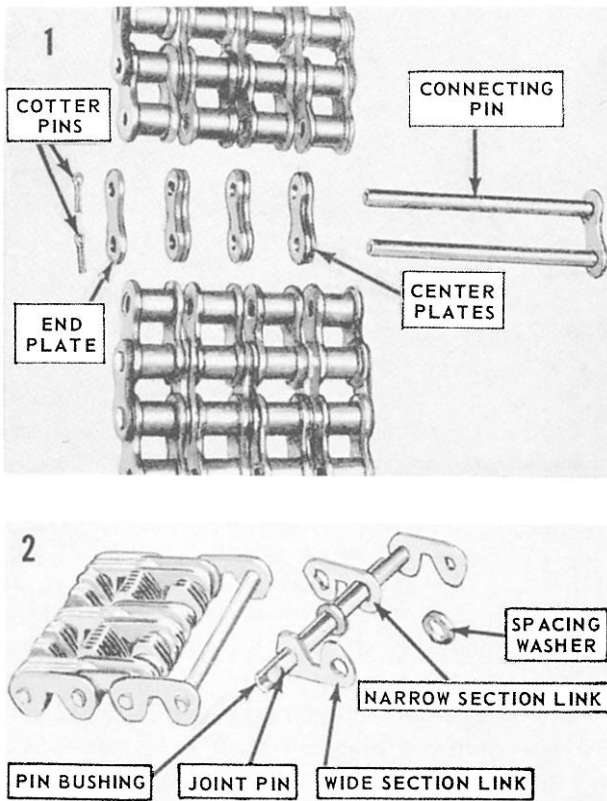
121.10

Figure 3-27.—Accessory drive chain link assemblies.

these inspections. An idler sprocket and chain tightener are used on most engines to adjust chain tension. During operation, chains increase slightly in length because of stretch and wear. Adjustments should be made for these increases whenever necessary.

When you are installing a new chain, peen the connecting link pins into place, but avoid excessive peening. After peening, make sure the links move freely without binding in position. Cotter pins must be secured or the joint pin ends riveted, whichever is applicable. Repair links should be carried at all times. Always check engine timing after installing a new timing and accessory drive mechanism.

TURBOCHARGERS

The turbochargers used in the Navy today may operate with temperatures as high as 1200 °F and

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speeds up to 75,000 rpm. Therefore, it is of utmost importance that turbochargers be maintained in proper working order at all times. If a turbocharger is allowed to operate without lubrication, cooling, or the proper clearances, it not only could be completely destroyed in a matter of minutes but also could possibly cause extensive damage to other machinery and personnel.

All oil lines and air duct connections should be inspected and free of leakage. The air filter should be clean and in place and there should be no build-up of dust or dirt on the impeller. Turn the impeller by hand and check for binding or rubbing and listen for any unusual noises.

When the turbocharger is operating, listen for any unusual noise or vibrations. If you hear a shrill high pitch whine, shut down the engine at once. The whine may be caused by a failing bearing, and serious damage may result. Do not confuse the whine heard as the turbine runs down with that of a bad bearing.

Noise from the turbocharger may also be caused by improper clearances between the turbine wheel and the turbine housing. The clearances should be checked at predetermined intervals in accordance with the PMS. Check bearing axial end play and shaft radial movement. Crankcase vents should not be directed towards the turbocharger air intakes, as the corrosive gases may cause pitting of the blades and bearings, thereby reducing the life of the turbocharger.